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FINAL

Fates and Effects of Exploratory Phase Oil and Gas Drilling Discharges in the Navarin Planning Area, Lease Sale 107

Prepared for:

U.S. Environmental Protection Agency
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March 10, 1989

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March 10, 1989

Ms. Sally Brough
U. S. Environmental Protection Agency
Environmental Evaluation Branch, WD-136
1200 Sixth Avenue
Seattle, WA 98101

Dear Ms. Brough:

Jones & Stokes Associates is pleased to transmit with this letter four copies of the Final EIS Appendix, "Fate and Effects of Exploratory Phase Oil and Gas Drilling Discharges in the Navarin Planning Area, Lease Sale 107," prepared under EPA Contract Number 68-02-4381, Work Assignment Number 19, with one camera-ready unbound copy of the document and a diskette of the text and tables in Word Perfect.

We have enjoyed working for you on this project and look forward to our continued association.

If you have any questions about the project, please do not hesitate to call myself or Harvey Van Veldhuizen.

Sincerely,

Carole Allen-Morley

Carole R. Allen-Morley, Ph.D.

CAM/bdg
Enclosures

FATE AND EFFECTS OF EXPLORATORY PHASE OIL AND GAS DRILLING DISCHARGES IN THE NAVARIN PLANNING AREA, LEASE SALE 107

U. S. ENVIRONMENTAL PROTECTION AGENCY
REGION 10

Developed with the assistance of:

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Table of Contents

List of Tables

List of Figures

INTRODUCTION

PURPOSE OF EVALUATION

The U. S. Environmental Protection Agency (EPA) intends to issue a National Pollutant Discharge Elimination System (NPDES) general permit for effluent discharges associated with oil and gas exploration in the Outer Continental Shelf (OCS) Lease Sale 107 (Navarin Basin), located in the western Bering Sea. Sections 402 and 403 of the Clean Water Act (CWA) require that NPDES permits for such ocean discharges be issued in compliance with EPA's guidelines (Ocean Discharge Criteria authorized by Section 403 of the CWA) for preventing unreasonable degradation of ocean waters.

Section 301(c) of the CWA provides that the discharge of pollutants to ocean waters is unlawful except in the terms of an NPDES permit. Under EPA's regulations (40 CFR 122.28[a][2]), EPA may issue a single general NPDES permit to a category of point sources located within the same geographical area if the regulated point sources:

1) involve the same or substantially similar types of operations;

2) discharge the same types of wastes;

3) require the same effluent limitations or operating conditions;

4) require similar monitoring requirements; and

5) in the opinion of the EPA Regional Administrator, are more appropriately controlled under a general permit than under individual permits.

EPA Region 10 has decided that general permits are more appropriate for these types of discharges than individual permits, and EPA expects to issue a general permit for exploratory drilling operations for Sale 107 in the Navarin Basin. However, EPA may issue individual NPDES permits for areas requiring special consideration, such as areas of sensitivity or of biological concern, and may elect to issue individual NPDES permits for future development and production operations in the Sale 107 area.

Before EPA can issue an NPDES permit to a new source, an environmental review must be conducted pursuant to Section 511(c)(1) of the CWA. EPA expects to adopt the Sale 107 Final Environmental Impact Statement (EIS) in order to satisfy this requirement. Ocean discharges must also be evaluated with respect to the Ocean Discharge Criteria developed in accordance with Section 403(c) of the CWA. The agency therefore offered to be, and was accepted as, a cooperating agency in the development of the EIS. The Minerals Management Service (MMS) of the U. S. Department of the Interior (DOI) requested that EPA provide an appendix presenting the fate of exploration-phase deliberate discharges, and the effects of these discharges on receiving water quality and biological populations.

SCOPE OF EVALUATION

This document evaluates the effects of waste discharges as provided for by the general NPDES permit proposed for offshore oil and gas exploration in the western Bering Sea under federal OCS Sale 107. This evaluation is based only on deliberate wastwater discharges occurring during exploration. It does not include impacts from exploration caused by noise, construction, spills, or other factors, and does not include discharges during development and production.

CURRENT EVALUATION

The proposed Sale 107 contains 5,036 blocks encompassing 11.4 million hectares (28 million acres) bordering on the U.S.A./U.S.S.R. 1867 convention line. The blocks that comprise the proposed action are located in the Bering Sea, 48 to 360 kilometers (30 to 225 miles) from the western end of St. Matthew Island (Figure 1). St. Lawrence Island and the Pribilof Islands are 97 and 180 kilometers (60 and 110 miles), respectively, to the east of the Lease Sale area. Water depths of the Lease Sale area range from approximately 70 to 2,400 meters (230 to 7,874 feet) although the area between 100 and 240 meters (328-800 feet) is of major interest for petroleum exploration (EPA, 1984, p. 3, Deis, 1984, p. 25).

Three scenarios for development are presented by MMS (DOI, 1988). Each scenario assumes a different number of exploration and delineation wells, but it is expected that the average exploration/delineation well in the Navarin Basin will use approximately 444 tonnes (490 tons) of mud solids and will produce 589 tonnes (650 tons) of cuttings (DOI, 1988). Exploration and delineation wells are generally 3,100 meters (10,000 feet) deep and take two to five months to drill and test (DOI, 1985, p. 60).

The first scenario is for exploration only, which assumes that exploration activities will occur but economically recoverable hydrocarbons will not be discovered. A total of six exploration wells are projected, drilled between 1990-1993 and producing a total of 2,664 tonnes (2,940 tons) of drilling muds and 3,540 tonnes (3,900 tons) of cuttings (Table 1). Drilling is expected to be done by semisubmersible. Exploration during the winter

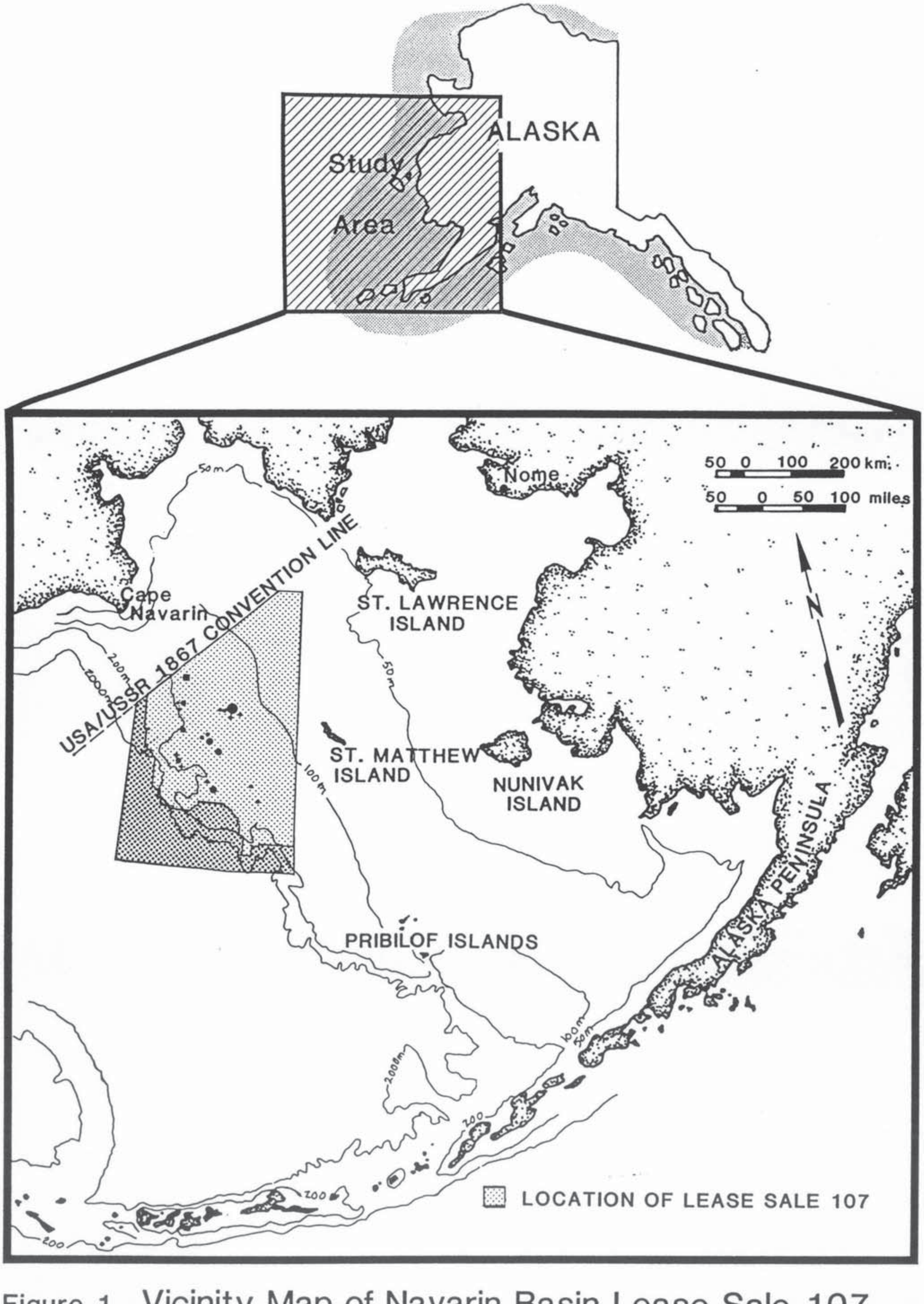


Figure 1. Vicinity Map of Navarin Basin Lease Sale 107.

Table 1
Estimated Annual Production of Drilling Muds and Cuttings
During Exploration and Delineation Activities
in the Navarin Basin, Lease-Sale 107[1/]

	Year	No. of Rigs	No. of Wells	Total Mud[2/] Tonne	Total Mud[2/] Ton	Total Cuttings[3/] Tonne	Total Cuttings[3/] Ton
Exploration Case	1990-1993	-	6	2,664	2,940	3,540	3,900
Base Case	1990	1	2	888	980	1,180	1,300
	1991	2	5	2,220	2,450	2,950	3,250
	1992	2	3	1,332	1,470	1,770	1,950
	1993	2	3	1,332	1,470	1,770	1,950
	1994	1	2	888	980	1,180	1,300
	1995	1	1	444	490	590	650
	Total		16	7,140	7,840	9,440	10,400
High Case	1990	3	6	2,664	2,940	3,540	3,900
	1991	6	12	5,328	5,880	7,080	7,800
	1992	6	12	5,328	5,880	7,080	7,800
	1993	5	10	4,440	4,900	5,900	6,500
	1994	4	8	3,552	3,920	4,720	5,200
	1995	2	5	2,220	2,450	2,950	3,250
	1996	2	4	1,776	1,960	2,360	2,600
	Total		57	25,308	27,930	33,630	37,050

Source: DOI, 1988

1/ Estimated number of wells and hypothetical drilling schedule.
2/ Each well assumed to use 444 tonnes (490 tons) of dry drilling mud.
3/ Each well assumed to produce 590 tonnes (650 tons) of cuttings.

season appears unlikely, but may be possible with ice-breaker support.

The second scenario is a base case projection, assuming the exploration phase results in the discovery of approximately 450 million barrels of commercially recoverable hydrocarbons. Twelve exploration wells and four delineation wells are projected, drilled between 1990-1995 and producing a total of 7,100 tonnes (7,840 tons) of drilling muds and 9,440 tonnes (10,400 tons) of cuttings (Table 1). Drilling is expected to be done by semisubmersible from a maximum of two rigs. Exploration during the winter season appears unlikely, but may be possible with ice-breaker support.

The third scenario is a high case projection, assuming the exploration phase results in the discovery of approximately 2,600 million barrels of commercially recoverable hydrocarbons. Activity is assumed to continue through 1990-1996, and 42 exploration wells and 15 delineation wells are projected. Approximately 25,308 tonnes (27,930 tons) of drilling muds and 33,630 tonnes (37,050 tons) of cuttings are expected to be produced in these six years (Table 1). Drilling is expected to be done by semisubmersible from a maximum of six rigs.

ORGANIZATION OF EVALUATION

The factors evaluated in this document are:

- various methods of drilling muds and cuttings disposal to the marine environment, including shunting and pre-dilution options, and discharges in open water, under broken ice, and under solid ice;
- the composition and quantities of materials discharged;
- the fate and transport of materials discharged;
- the effects of discharges with reference to applicable marine water-quality criteria;
- the effects of discharges upon the biotic community; and
- the implications of land-disposal (no discharge) of discharges.

DESCRIPTION OF ALTERNATIVES

This section discusses the alternatives available under the CWA, including the granting of an NPDES permit and technology-based effluent limitations, and briefly reviews alternative development scenarios.

CLEAN WATER ACT PERMIT REQUIREMENTS

Sections 301(b), 304, 306, 308, 401, and 403(c) of the CWA provide the basis for NPDES permit conditions. The general requirements of these sections fall into two categories, ocean discharge criteria and technology-based effluent limitations. These sections are described below.

OCEAN DISCHARGE CRITERIA

EPA's Ocean Discharge Criteria (40 CFR Part 125, Subpart M) set forth specific determinations of unreasonable degradation that must be made prior to permit issuance. "Unreasonable degradation of the marine environment" is defined as (40 CFR 125.121[e]):

"(1) Significant adverse changes in ecosystem diversity, productivity and stability of the biological community within the area of discharge and surrounding biological communities,

(2) Threat to human health through direct exposure to pollutants or through consumption of exposed aquatic organisms, or

(3) Loss of aesthetic, recreational, scientific or economic values, which is unreasonable in relation to the benefit derived from the discharge."

The determination of unreasonable degradation must be based on the following factors: quantities, composition, and potential for bioaccumulation or persistence of the pollutants discharged; potential transport of such pollutants; the composition and vulnerability of the biological communities exposed to such pollutants; the importance of the receiving-water area to the surrounding biological community; the existence of special aquatic sites; potential effects on human health; effects on recreational and commercial fishing; applicable requirements of approved Coastal Zone Management Plans; marine water-quality criteria developed pursuant to section 304(a)(1) of the CWA; and other relevant factors.

If the EPA Regional Administrator determines that the discharge will not cause unreasonable degradation of the marine environment based upon the above criteria, an NPDES permit may be issued. If the Regional Administrator determines that the discharge will cause unreasonable degradation of the marine environment, an NPDES permit may not be issued.

If the Regional Administrator has insufficient information to determine prior to permit issuance that there will be no unreasonable degradation of the marine environment, an NPDES permit may not be issued unless the Regional Administrator, on the basis of the best available information, determines that: 1) such discharge will not cause irreparable harm (as defined in 40 CFR 125.121[a]) to the marine environment, 2) there are no reasonable alternatives to the on-site disposal of these materials, and 3) the discharge will be in compliance with certain specified permit conditions (40 CFR 125.122).

TECHNOLOGY-BASED EFFLUENT LIMITATIONS

The CWA requires particular classes of industrial discharges, including those associated with oil and gas exploratory drillings, to meet technology-based effluent limitations established by EPA. The CWA provides for implementation of these effluent limitations in three stages.

Best practicable control technology currently available (BPT) was required no later than July 1977. BPT represents the average of the best existing performances of well-known technologies for control of traditional pollutants. EPA set effluent-limitation guidelines requiring BPT for the Offshore Subcategory of the Oil and Gas Extraction Point Source Category (40 CFR Part 435, subpart A) on April 13, 1979 (44 FR 22069). BPT for this subcategory limits the discharge of oil and grease in produced water to a daily maximum of 72 milligrams per liter and a 30-day average of 48 milligrams per liter; prohibits the discharge of free oil that would cause a sheen on the water surface in deck drainage, drilling fluids, drill cuttings, and well-treatment fluids; requires a minimum residual chlorine content of 1 milligram per liter in sanitary discharges; and prohibits the discharge of floating solids in sanitary and domestic wastes.

Toxic pollutants are controlled by the best-available technology economically achievable (BAT) (40 CFR 401.15), while conventional pollutants, such as oil and grease, biochemical oxygen demand, pH, suspended solids, and fecal coliforms, are controlled by the best conventional-pollutant control technology (BCT). Controls by BAT and BCT are to be achieved as expeditiously as practicable, but in no case later than three years after the date of final promulgation of technology-based guidelines, and in no case later than March 31, 1989. In no case are BAT or BCT to be less stringent than the already existing BPT. Permits must impose effluent limitations which control non-conventional (i.e., neither toxic nor conventional) pollutants by means of BAT no later than March 31, 1989.

Finally, effluent limitations based on the best-demonstrated control technology must be imposed with the development of new-source performance standards (NSPS).

BAT/BCT effluent-limitation guidelines and NSPS for the Offshore Subcategory were proposed by EPA in August 1985 (50 FR 34592). Promulgation of these guidelines and standards is not expected until 1990, although proposed rules have been published (53 FR 41358). The proposed rules include: 1) no discharge of free oil as determined by the static sheen test prior to discharge (applicable to BAT and BCT); 2) the 96-hour LC50 toxicity of discharged drilling fluids to be limited to 3.0 percent by volume, at a minimum; 3) mercury and cadmium each to be less than 1 milligram per kilogram drilling fluid discharged; and 4) the continued prohibition on the discharge of diesel oil. The proposed regulations would establish NSPS limitations for free oil, diesel oil, toxicity, mercury and cadmium as described for BAT.

EPA Region 10 BAT requirements in permits 1) prohibit the discharge of all oil-based muds, diesel oil, and cuttings with either an oil content greater than 10 percent, or cuttings which contain diesel oil, or those that cause a sheen; 2) limit the mercury and cadmium content of barite to 1 milligram per kilogram and 3 milligrams per gram (dry weight basis), respectively; 3) set limits for the biochemical oxygen demand of sanitary-waste and requires a residual chlorine content of no less than 1.0 milligram per liter in the wastes; 4) set toxicity limitations on drilling fluids; and 5) set other limits on miscellaneous discharges. Such requirements were incorporated in the general permits for the Bering and Beaufort Seas (49 FR 23734, June 7, 1984), for Norton Sound (50 FR 23578, June 4, 1985), and for Cook Inlet (EPA, 1988a).

ALTERNATIVE DEVELOPMENT SCENARIOS

The proposed OCS Sale 107 in the Navarin Basin Planning Area is tentatively scheduled for 1990. Three scenarios are under consideration. The number of exploration and delineation wells range from six (exploration only scenario) to 57 (high case scenario). Similarly the quantities of muds and cutting produced ranges widely. A summary is provided in Table 1.

Six alternatives are under consideration: 1) the proposed action consisting of three alternative scenarios; 2) no action, in which case no drilling would occur in the basin; 3) the proposed action delayed for two years; 4) no activity within 80 kilometers (50 miles) of St. Matthew Island (no activity is projected within 80 kilometers of the island so this is essentially the same as the proposed action); 5) deferral of blocks beyone the 200-meter isobath (assumed economically inviable so this is essentially the same as no action); and 6) five-year leasing program highlighting subarea deferral (no activity is projected within the deferral area so this is essentially the same as the proposed action).

Land-disposal must be considered as the alternative to ocean disposal of drilling muds if the NPDES permit conditions are not met or if there is insufficient information to determine that there will be no unreasonable degradation to the marine environment. Land-disposal is very difficult in the Navarin Basin Lease Sale area because the minimum distance from Navarin Basin to land is 32 kilometers (20 miles). Nevertheless, this option is explored on page 70 of this appendix.

COMPOSITION AND QUANTITY OF MATERIALS DISCHARGED

This section describes and quantifies the various discharges expected from oil and gas drilling rigs during exploratory and delineation activities. Attention is given to the drilling muds and the specialty additives they contain.

TYPES OF DISCHARGES

Exploratory oil and gas well drilling can produce a wide range of waste materials related to the drilling process, maintenance of equipment, and personnel housing. The major discharges to be expected from exploratory drilling are drilling fluids (muds) and cuttings. Other discharges may include sanitary and domestic wastes, desalination-unit discharge, boiler blowdown, test fluids, deck drainage, cooling water, blowout-preventer fluid, ballast and bilge water, and excess cement slurry.

MISCELLANEOUS DISCHARGES

Sanitary-waste discharge is expected to be under 5,300 liters (1,400 gallons) per day per rig (Menzie, 1983), which consists of chlorinated, perhaps secondary treated, effluent. Upon discharge, immediate dissolved oxygen demand is exerted, which represents the oxygen demand of organic compounds that are rapidly oxidized. Calculations described in EPA (1984) indicate that the dissolved oxygen depression resulting from the discharge of treated sewage effluent during offshore exploratory drilling will not be significant when ambient dissolved oxygen concentrations are at least 1 milligram per liter above the dissolved oxygen standard for aquatic life, usually 6 milligrams per liter. Since the ambient dissolved oxygen concentration in the Bering Sea varies from 10 milligrams per liter at the surface to 8.5 milligrams per liter at a depth of 50 meters (160 feet) (Hood, 1981), sewage effluent discharge is not expected to significantly impact dissolved oxygen concentrations in the ocean.

Desalination-units may discharge on the order of 757,000 liters (200,000 gallons) per day per rig of water having salinity twice that of ambient seawater. Biocides in desalination-unit water could result in significant mass loadings of pollutants into the immediate marine environment if the chemicals are not consumed or significantly detoxified prior to discharge. Boiler blowdown may be discharged once or twice a year per rig in volumes of around 230 liters (60 gallons). Both of these discharges may contain biocides or chemicals used to combat corrosion and scaling. The volume of boiler blowdown is so small that it is unlikely to be a significant source of pollution.

Test fluids are discharged from the well upon completion of drilling. These may consist of formation water, oil, natural gas, formation sands, any acids or chemicals added downhole, or any combination thereof. Test fluids are generally stored and treated for oil removal and pH before being discharged or flared. Approximately 1 percent of the total test fluids will have a pH of 2. During a typical 5-day well test, this may involve 8,000 liters (50 barrels) of water. The addition of strong acidic fluids downhole could cause significant leaching of heavy metals from the formation and residual drilling muds. The remaining test fluids will have a pH of 5 to 8.5, with about 97 percent of the volume above pH 6.5. The permit will require neutralization (pH 6.5-8.5) of all spent acidic fluids before discharge.

Deck drainage, consisting of precipitation and wash-water from the deck and drilling floor, is reported as 53,000 liters per day (14,000 gallons per day) (Menzie, 1983). Gutters normally carry the drainage to a sump tank where oil is separated and removed before the water is discharged. Oil is the primary pollutant in deck drainage, with a reported range of 24 to 450 milligrams per liter, but these discharges may also contain small quantities of detergents used in cleaning procedures and spilled drilling mud or chemicals (Mors et al., 1982, pp. 2-38).

The volume of noncontact cooling water can vary depending on the system used. Closed-system, air-cooled designs require no cooling water, whereas other systems may discharge 0.38 to 3.8 million liters (10^5 to 10^6 gallons) per day. Reported temperatures range from 15° to 25°C (62° to 84°F), much higher than ambient seawater. Biocides may be used to control fouling in the heat exchange units (Zimmerman and de Nagy, 1984, p. 1). The volumes of cooling-water discharge could result in significant mass loadings of pollutants into the immediate marine environment if the chemicals are not consumed or significantly detoxified prior to discharge.

Bilge waters are treated for removal of oil prior to discharge. Ballast waters are not treated; however, the permit will prohibit discharges that produce an oil sheen.

The primary constituents of blowout-preventer fluid are ethylene glycol and water. The volume of fluid discharged when the device is actuated is not well documented. Mors et al. (1982, pp. 1-12) state that a representative discharge estimate obtained from industry discharge monitoring reports (DMRs) is 760 liters (200 gallons) per day. The primary chemical constituent, ethylene glycol, is not highly toxic; Zajic and Himmelman (1978, p. 23) consider the hazard of this compound to be "minor." Some proprietary formulations are used; their hazard cannot be assessed.

Cement will be discharged on the ocean floor in the early phases of drilling (before the well casing is set) and during well abandonment and plugging. Excess cement slurry will result from equipment washdown after cementing operations. The composition of the cement is not documented, but is not expected to be a significant pollutant source.

In summary, discharges other than drilling mud and cuttings are expected to represent only small pollutant loadings from offshore exploratory drilling operations with properly designed and functioning equipment. Cooling-water and desalination-unit discharges could result in pollutant loadings from biocides, corrosion inhibitors, and scale preventers. Because detailed information is not available on quantities or composition of these chemicals, the following monitoring appears warranted:

- Heavy-metal concentrations in spent test fluids should be determined.

- Cooling-water and desalination-unit discharges (and any other high volume discharge) should be monitored for volume of discharge and the chemical composition and concentration of biocides, corrosion inhibitors, or other chemical additives.

COMPOSITION OF DRILLING MUD

GENERAL COMPOSITION

Drilling mud is a complex mixture of clay, barite, and several specialty additives used primarily to remove rock particles from the hole created by the drill bit. Additionally, drilling mud serves several other functions including creating pressure to counteract pressure in the formation at depth, lubricating the drill bit, and controlling the flow of fluids between the formation and the hole. The composition of drilling mud can vary over a wide range from one hole to the next, as well as during the completion of a single hole.

Six generic mud-types have been evaluated and approved for discharge by EPA. Table 2 lists the basic components of each mud and their maximum authorized concentrations. Each mud differs in its basic components, and a single mud-type can vary substantially in composition.

METALS

The presence of potentially toxic trace elements in drilling muds and cuttings is of concern. Metals, including lead, zinc, mercury, arsenic, vanadium, and cadmium, can be present as impurities in barite; chromium is present in chrome lignosulfonates

Table 2
Authorized Drilling-Mud Types

Components	Maximum Allowable Concentration (lb/bbl)	Components	Maximum Allowable Concentration (lb/bbl)
1. Seawater/Freshwater/Potassium/Polymer Muds		4. Non-Dispersed Mud	
KCl	50	Bentonite	50
Starch	12	Acrylic Polymer	2
Cellulose Polymer	5	Lime	2
Xanthum Gum Polymer	2	Barite	180
Drilled Solids	100	Drilled Solids	70
Caustic	3	Seawater/Freshwater	As Needed
Barite	575		
Seawater/Freshwater	As Needed		
		5. Spud Mud	
2. Seawater/Lignosulfate Mud		Lime	2
		Bentonite[1/]	50
Bentonite[1/]	50	Caustic	2
Lignosulfate, Chrome, or Ferrochrome	15	Barite	50
Lignite, Untreated or Chrome-treated	10	Soda Ash/ Sodium Bicarbonate	2
Caustic	5	Seawater	As needed
Lime	2		
Barite	575		
Drilled Solids	100	6. Seawater/Freshwater Gel Mud	
Soda Ash/Sodium Bicarbonate			
Cellulose Polymer	5	Lime	2
Seawater/Freshwater	As Needed	Bentonite[1/]	50
		Caustic	3
		Barite	50
3. Lime Mud		Drilled Solids	100
		Soda Ash/Sodium Bicarbonate	2
Lime	20	Cellulose Polymer	2
Bentonite[1/]	50	Seawater/Freshwater	As Needed
Lignosulfate, Chrome, or Ferrochrome	15		
Lignite, Untreated or Chrome-treated	10		
Caustic	5		
Barite	575		
Drilled Solids	100		
Soda Ash/Sodium Bicarbonate	2		
Seawater/Freshwater	As Needed		

Source: EPA, 1986

1/ Attapulgite, sepiolite, or montmorillonite may be subsituted for bentonite.

and chrome-treated lignite (Kramer et al., 1980, p. 789; Crippen et al., 1980, pp. 639-640; Menzie, 1982, p. 471). According to Ayers et al. (1980, p. 389) and Ecomar (1978, p. 42), drill-pipe dope (15 percent copper, 7 percent lead) and drill-collar dope (35 percent zinc, 20 percent lead, 7 percent copper) also contribute trace metals to the muds and cuttings discharge.

Trace-metal concentrations expected in drilling muds used in oil and gas exploratory drilling are given in Table 3. Two values are given. The metals content of the generic muds prior to use were analyzed by CENTEC (1984) and these values are reported in Column 1. The metals content of the discharges, which consist of both generic muds and additives, are reported in DMRs. Maximum metal concentration values from the reported data are given in Column 2. The difference in concentrations is substantial for barium, cadmium, chromium, lead, mercury, nickel, and zinc. Arsenic and copper change very little. This difference can be attributed to authorized specialty additives, incidental contamination from pipe dope, and differences in laboratory analyses and sample sources.

The range of metal concentrations in the drilling discharge is compared to average concentrations of the metals observed in the Earth's continental crust and in Alaskan OCS sediments (Table 4). With the exception of nickel and copper, all the listed metals can occur at concentrations greater than average continental crust or Alaskan OCS sediments. Barium in drilling muds is present at two orders of magnitude or greater concentration than any other trace metal.

CHROME LIGNOSULFONATES

Chrome lignosulfonates are present in two of the six generic muds approved for offshore drilling. When added to drilling fluids, chrome lignosulfonates adsorb to the clay component, inhibiting flocculation and loss of viscosity during use. However, chrome lignosulfonates are readily soluble in water (approximately 500 grams per liter [Knox, 1978]), and the extent that they may be displaced from drilling muds during use, or by seawater ions after discharge, has not been determined. Chrome lignosulfonates resist decomposition and persist in the marine environment for long periods of time. They are a major source of chromium, and their impacts on the biota will be addressed in a later section. The proportion of total chromium in the discharge that is actually combined with used lignosulfonates is unknown (Liss et al., 1980, pp. 691-695).

Marine sediments are the likely repository for discharged chrome lignosulfonates although the fate of these compounds in marine sediments is unclear. Because they are water-soluble, the potential exists for slow release into sedimentary pore-waters and/or reintroduction into bottom-waters by resuspension or

Table 3
Selected Trace Metal Concentrations Expected in Generic Drilling Muds and in Muds and Additives Discharged in Alaskan Waters

Metal	Maximum Concentration (mg/kg)	
	Generic Muds1/	Muds Discharged in Alaskan Waters2/
Arsenic	17.2	11.8
Barium	1,240	298,800
Cadmium	0.7	5.5
Chromium	908	1,820
Copper	77.3	47.7
Lead	52.5	1,2703/
Mercury	0.7	194/
Nickel	9.8	885/
Vanadium	N.A6/	2355/
Zinc	90.4	3,420

1/ CENTEC (1984). The muds were hot-rolled prior to analysis to simulate chemical changes induced by downhold conditions.

2/ EPA (1988b). Reported in mg/kg solids.

3/ Only one operator, using Generic Mud #8, discharged muds with this high concentration of lead. The average of 100 records is 33.1 mg/kg with a standard deviation of 127.8 mg/kg.

4/ Only one operator, using Generic Mud #7, discharged muds with this high concentration of mercury. The average of 100 records is 0.36 mg/kg with a standard deviation of 1.86 mg/kg.

5/ Northern Technical Service, 1981, p. 91. Reported in ppm drilling fluid.

6/ Not available.

Table 4
Comparison of the Range of Trace Metal Concentrations in Standard Drilling Muds and Average Earth's Continental Crust

Metal	Drilling Muds1/ (mg/kg dry weight of whole mud)	Continental Crust2/ (mg/kg)	Alaska OCS3/ (mg/kg)
Arsenic	11.8	1.8	-
Barium	298,800	425	-
Cadmium	5.5	0.15	<0.1
Chromium	1,820	120	1.7 - 3.2
Copper	48.7	60	<0.3 - 31
Lead	1,270	14	-
Mercury	19	0.08	0.011 - 0.067
Nickel	88	84	<1.3 - 13
Vanadium	235	120	-
Zinc	3,420	70	0.9 - 39

1/ From Table 3. Maximum metals concentration of muds and additives discharged to Alaskan waters.
2/ Ronov and Yaroshevsky, 1972, pp. 252-254.
3/ Burrell, 1978, pp. 281-329. Values for extractable concentrations from sediment.

bioturbation, increasing their availability to marine organisms. All evidence points to minimal degradation by either abiotic (strictly chemical) degradation (Sarkanen and Ludwig, 1971, p. 916) or microbial breakdown (Hackett et al., 1977, pp. 50-51; Crawford, 1981, pp. 4-8). This evidence is supported by published studies of lignin distributions in marine sediments that indicate minimal in situ degradation periods in excess of 10,000 years (Hedges and Van Green, 1982, pp. 53-54). This indicates that chrome lignosulfonates will persist in the sediments for long periods of time.

SPECIALTY ADDITIVES

In addition to the substances listed in Table 2 that make up the six generic mud-types approved for use by EPA, a group of downhole additives are used for specific problems that may be encountered in the course of drilling. These additives can range from simple inorganic salts to complex organic polymers. Table 5 lists the more common additives in water-based drilling muds. Among the additives used in large enough quantities to result in significant mass loadings to the environment are: spotting materials, lubricants, zinc compounds, biocides, and materials added to prevent loss of circulation.

Spotting materials are used to help free stuck drillstrings. Some of these (e.g., vegetable oil or fatty acid glycerol) are easily broken down in the environment. The most effective and consequently most frequently used spotting compounds are oil-based. In normal situations, 8,000 to 32,000 liters (50 to 200 barrels) of spotting material are sent downhole in a concentrated pill (not diluted throughout the mud system) (Bechenmire, pers. comm.). Furthermore, concentrations within the pill may approach 100 percent oil. If the drillstring remains stuck, the pill of spotting material is left downhole with the abandoned drillstring. When the drillstring is unstuck, the spotting material can sometimes be brought out as a plug to a separate holding tank and residual oil content in the mud will remain at approximately 2 percent. However, if the oil is left to mix with the drilling muds, average concentrations of up to 10 percent oil can be reached in the drilling muds.

Lubricants are added to the drilling mud when high torque conditions are encountered on the drillstring. These lubricants can be vegetable or mineral oil or asphalt-based compounds such as Soltex. When needed, these lubricants are used to treat the entire mud system (roughly 320,000 liters [2,000 barrels]) with concentrations of about 5.5 to 11 kilograms per cubic meter (2 to 4 pounds per barrel) expected in Bering Sea drilling operations (Bechenmire pers. comm.). Elsewhere, concentrations up to 140 kilograms per cubic meter (50 pounds per barrel) have been noted. If they were to be discharged with the muds, approximately 1,800

Table 5
Authorized Mud Components/Specialty Additives

Product Name	Generic Description[1/]	Maximum Allowable Concentration (lb/bbl unless otherwise noted)[2/]
Aktflo-S	Aqueous solution of non-ionic modified phenol (equivalent of DMS)	3[2/]
Aluminum stearate	----	0.2
Ammonium nitrate	----	200 mg/L nitrate or 0.05 lb/bbl
Aqua-Spot	Sulfonated vegetable ester formulation	1% by vol.
Bara Brine Defoam	Dimethyl polysiloxane in an aqueous emulsion	0.1
Ben-Ex	Vinyl acetate/maleic anhydride copolymer	1[2/]
Bit Lube II	Fatty acid esters and alkyl phenolic sulfides in a solvent base	2
Calcium carbide	----	As needed
Cellophane flakes	----	As needed
Chemtrol-X	Polymer treated humate	5[2/]
Con Det	Water solution of anionic surfactants	0.4[2/]
D-D	Blend of surfactants	0.5[2/]
DMS	Aqueous solution of nonionic modified phenol	3[2/]
Desco CF	Chrome-free organic mud thinner containing sulfomethylated tannin	0.5

Product Name	Generic Description[1/]	Maximum Allowable Concentration (lb/bbl unless otherwise noted)[2/]
Duovis	Xanthan gum	2
Durenex	Lignite/resin blend	6[2/]
Flakes of silicate mineral mica	----	45
Gelex	Sodium polyacrylate and polyacrylamide	1[2/]
Glass beads	----	8
LD-8	Aluminum stearate in propoxylated oleylalcohol	10 gal/1500 bbl
Lube-106	Oleates in mixed alcohols	2
Lubri-Sal	Vegetable ester formulation	2.0% (by vol)
MD (IMCO)	Fatty acid ester	0.25[2/]
Milchem MD	Ethoxylated alcohol formulation	0.04 gal/bbl or 0.3 lb/bbl[2/]
Mil-Gard	Basic zinc carbonate	As needed
Nut hulls, crushed granular	----	As needed
Phosphoric acid esters and triethanolamine	----	0.4
Plastic spheres	----	8
Poly RX	Polymer treated humate	4[2/]
Resinex	Reacted phenol-formaldhyde-urea resin containing no free phenol, urea, or formaldehyde	4[2/]
Selec-Floc	High molecular weight poly-acrylamide polymer packaging in light mineral oil	0.25
Sodium chloride	----	50,000 mg/L chloride

Product Name	Generic Description[1/]	Maximum Allowable Concentration (lb/bbl unless otherwise noted)[2/]
Sodium nitrate	----	200 mg/L nitrate or 0.05 lb/bbl
Sodium polyphosphate	---	0.05
Soltex	Sulfonated asphalt residuum	6
Sulf-X ES	Zinc oxide	As needed
Therma Check	Sulfono-acrylamide copolymer	1
Therma Thin	Polycarboxylic acid salt	4
Torq-Trim II	Liquid triglycerides in vegetable oil	6
Vegetable plus polymer fibers, flakes, and granules	----	50
VG-69	Organophilic clay	12
XC Polymer	Xanthan gum polymer	2
XO_2	Ammonium bisulfite	0.5
Zinc carbonate and lime	----	As needed

Source: EPA, 1986

1/ Any proprietary formulation that contains a substance which is an intentional component of the formulation, other than those specifically described, must be authorized by the Director.

2/ If a listed product will be used in combination with other functionally equivalent products, the maximum allowable concentration (MAC) for the sum of all of the products is the lowest MAC for any of the individual products. Four examples of functionally equivalent products are: (1) Aktaflo-S and DMS, MAC = 3 lb/bbl; (2) Ben-Ex and Gelex, MAC = 1 lb/bbl; (3) Chemtrol-X, Durenex, Poly RX, and Resinex, MAC = 4 lb/bbl, and (4) Con Det, D-D, MD (IMCO), and Milchem MD, MAC = 0.25 lb/bbl. For these examples, the MAC for any combination of the products is given in parentheses. For guidance on whether other products are considered to be functional equivalents, contact the regional office of EPA.

to 3,600 kilograms (4,000 to 8,000 pounds) of lubricants would be discharged into the Bering Sea from each treatment of the system.

Zinc compounds (e.g., zinc carbonate) are used as sulfide scavengers when formations with hydrogen sulfide are encountered. The entire mud system is treated with zinc compounds as needed. Typically, concentrations of 1.5 to 5.5 kilograms zinc compounds per cubic meter of mud (0.5 to 2 pounds per barrel) are used, resulting in 450 to 1,800 kilograms (1,000 to 4,000 pounds) of zinc carbonate (240 to 940 kilograms [520 to 2,080 pounds] of zinc) in the drilling mud. The zinc sulfide and unreacted zinc compounds are discharged with the drilling mud into the environment.

In cases of lost circulation to the mud system, combinations of cellophane, mica, and walnut hulls are added to the mud in one of two methods. The entire system can be treated with typically 0.2-2.0 kilograms (0.5 to 5 pounds) per barrel, which results in 220-2,200 kilograms (1,000-10,000 pounds) of the additives to the system. Alternately, a pill of 100 to 200 barrels with a concentration of 9-27 kilograms (20-60 pounds) per barrel can be sent downhole (Bechenmire, pers. comm.). When drilling is resumed, the additives are separated out from the drilling mud and discharged with the cuttings into the environment; the muds are reused.

COMPOSITION OF CUTTINGS

The trace-metal concentrations listed for the earth's continental crust are an indicator of the concentrations to be expected in the cuttings. It should be noted, however, that the trace-metal concentrations in mud and the natural rock could vary well beyond the concentration range noted in Table 4. Most of the trace metals in the cuttings are likely to be located in the mineral structure of the rock formation. Cuttings typically occur as granular material similar to coarse sand.

QUANTITY OF DRILLING MUDS AND CUTTINGS

The total number of wells to be drilled in the Navarin Basin Lease Sale 107 during exploratory and delineation operations has been estimated by MMS to be a maximum of 57 wells for purposes of impact evaluation (DOI, 1988). These wells will be drilled over a six-year period. Three wells could be drilled from a single site in one calendar year, although two wells are more likely to be drilled from a single rig in one year (DOI, 1988).

Each well is expected to use an average of 444 tonnes (490 tons) of dry mud and to produce 589 tonnes (650 tons) of drill cuttings. This is equivalent to 1,960 barrels, assuming 227 kilograms mud per barrel (500 pounds per barrel). It is assumed that each well will be completed within a two- to five-month time-frame (DOI, 1985, p. 60). Using these estimates for muds and cuttings production, the expected mass loadings are presented in Table 1.

The rate of discharge during a well drilling operation is quite variable. There are periods of no discharge when drill bits are changed or casing is placed. During the actual drilling and circulation of the drilling mud, cuttings are brought up from the hole, removed by solids control equipment (approximately 90 to 95 percent efficient), and discharged relatively continuously. Drilling mud is discharged in bulk when mud-type is changed, during cementing operations, or at the end of drilling. Bulk discharge rates have been reported to range from 4,800 to 190,000 liters per hour (30 to 1,200 barrels per hour) with the total volumes discharged each time ranging from 15,900 to over 320,000 liters (100 to 2,000 barrels).

FATE AND TRANSPORT OF MUDS AND CUTTINGS DISCHARGES

This assessment relies extensively on the results of computer simulation modeling of dispersion and dilution of drilling muds. Oceanographic conditions are briefly described, then the model is presented, and the results of the modeling runs are discussed.

THE NAVARIN BASIN OCEANOGRAPHIC CONDITIONS

The Lease Sale area encompasses the outer continental shelf, the shelf break, and deeper oceanic waters. Water depths range from 70 meters (230 feet) to over 2,800 meters (9,200 feet) (EPA, 1984, p. 3). Many of the Navarin Basin lease tracts are located on the outer shelf between the 100- and 200-meter (330- and 660-foot) isobaths.

METEOROLOGY

The area has a mean monthly temperature of less than 10°C (50°F), and the precipitation is uniformly distributed throughout the year. The area is generally windy; summer winds are from the south and southwest at speed of 4-8 meters per second (7-16 knots), and winter winds are from the north and northeast at speeds of 8 meters per second (17 knots). Intense winter storms produce exceptionally large waves which are capable of eroding bottom sediment (Karl and Carlson, 1983, p. 399).

CIRCULATION

The Alaska Stream flows westward along the Aleutians and enters the Bering Sea through passes in the Aleutian Island chain. Currents flow east, then northwest through the Navarin Basin, branching in the Navarin Basin area to form two currents: one to the northeast (towards the Bering Strait) and one to the southwest (Figure 2). Up to 50 percent more water exchange between the Pacific and Bering Seas occur in the winter due to a 10-fold

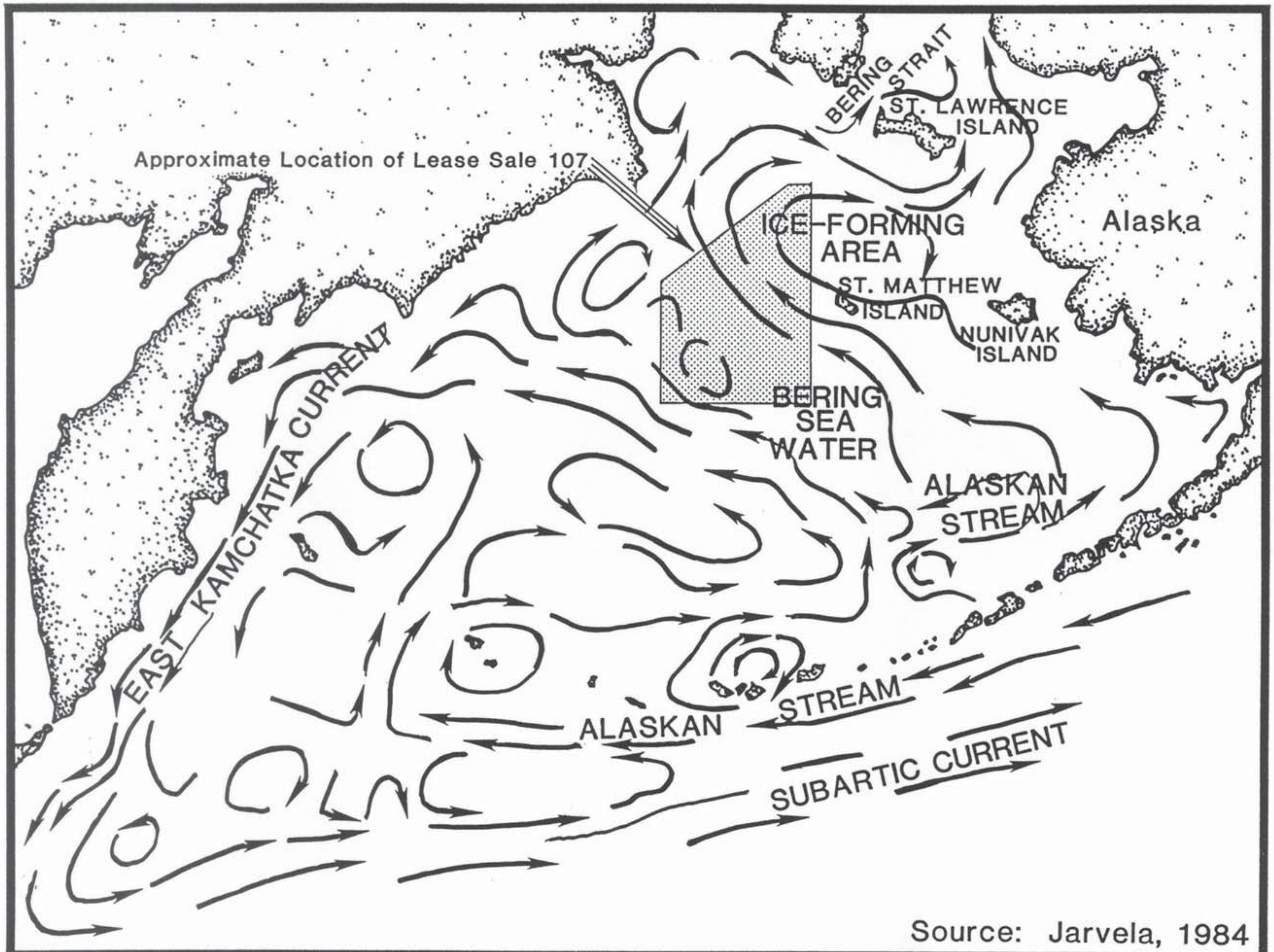


Figure 2. General Description of Circulation in the Bering Sea.

increase in wind stress on the water surface. Water masses to the southwest of St. Lawrence Island flow in a clockwise gyre (Figure 2).

Current speeds range from a few centimeters per second to 5-10 centimeters per second (0.1-0.2 knots) exclusive of wind-driven contributions (Jarvela, 1984). Along the continental slope and in some eddies mean speeds range 10-15 centimeters per second (0.2-0.3 knots) (Takenouti and Ohtani, 1974, p. 41). Water velocities in the winter are 1.2-1.7 times those of the summer. Tides in the Bering Sea are predominately mixed, semidiurnal, and of moderate amplitude. Mean tidal ranges for locations near the basin are 0.6 meter (2.0 feet) at St. Lawrence Island to 0.4 meter (1.3 feet) at St. Matthew Island (Department of Commerce, 1983, p. 186).

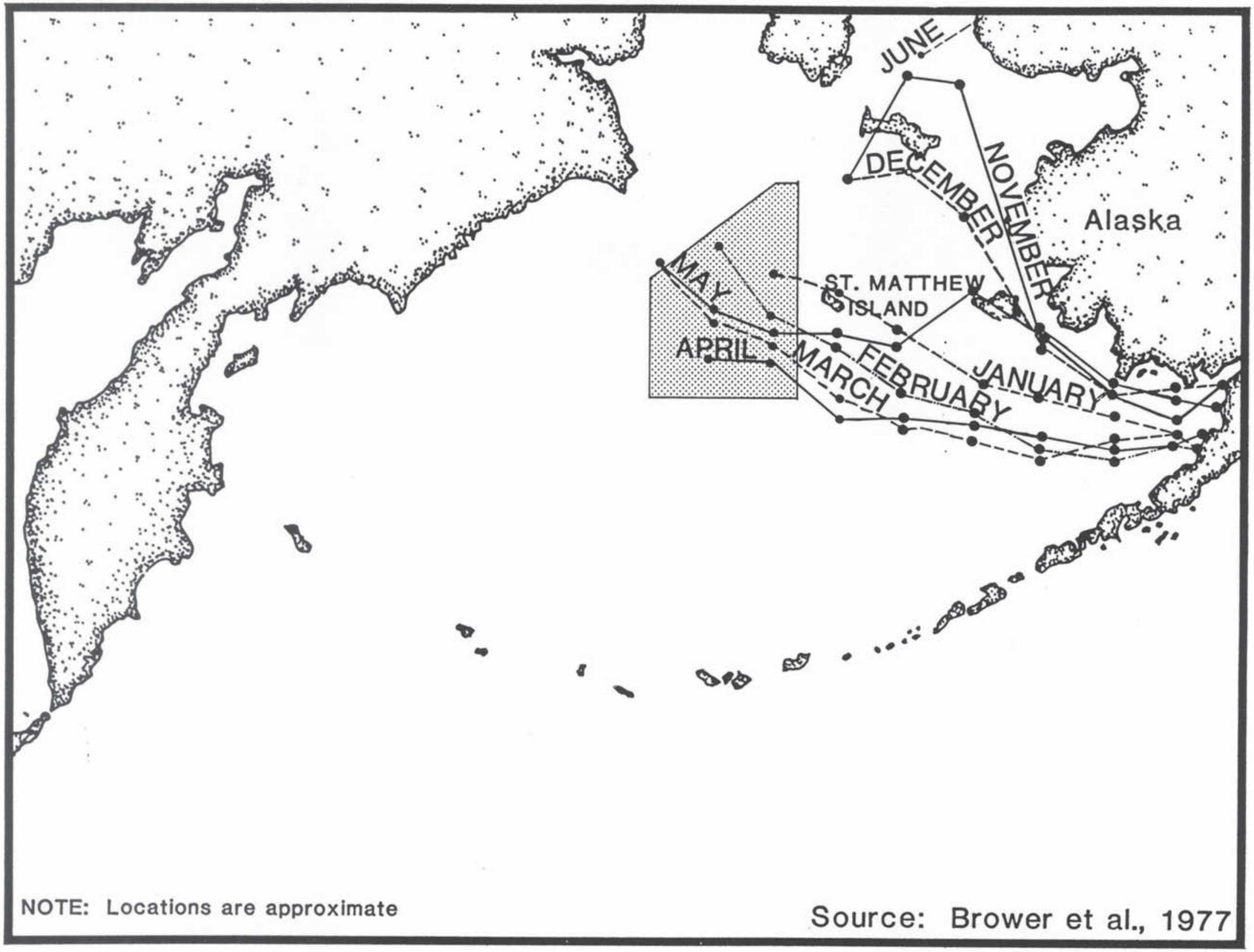
The water column of the Bering Sea consists of four layers: a surface layer, an intermediate cold layer (Bering Sea water), an intermediate warm layer (Pacific Ocean water), and a deep layer. All four layers are present in the summer, but stratification decreases in the winter leading to a uniform surface layer of approximately 150 meters (500 feet) (Arsen'ev, 1967, p. 104). Vertical mixing of the water can reach the seafloor over the continental shelf.

ICE FORMATION AND MOVEMENT

The distribution and extent of sea ice in the Bering Sea varies greatly from year to year. Generally, the Bering Sea is entirely free of ice during the summer (July through October). Sea ice begins moving south in November, dominates the region from January through May, begins to recede in April, and by July all sea ice is located north of the Bering Strait. The maximum southerly extent of ice occurs in late March or early April (Figure 3) (Niebauer, 1980, p. 7,513).

The Bering Sea ice edge is made up of three zones: the edge zone, the transition zone, and the interior zone. The edge zone is roughly 5-10 kilometers (3-6 miles) wide and is made up of small, ridged floes 2-4 meters (7-13 feet) thick and 20 meters (66 feet) wide. In the transition zone (approximately 5 kilometers [3 miles] wide), ocean swell fractures the pack ice into small rectangular floes approximately 20 meters (66 feet) in diameter but only 0.3-0.6 meter (1-2 feet) thick. The interior zone consists of thin, extensive floes, 0.2-0.3 meter (0.7-1.0 foot) thick and several kilometers in diameter (Martin and Bauer, 1981, pp. 189-210).

Currents and water circulation in the area should not be significantly altered by drift ice, but pack ice will reduce wind and tidal currents significantly, resulting in reduced dispersion of discharges. Ice-cover may also significantly dampen winter storm activity (Sharma, 1979, p. 351). Exploration activity during



NOTE: Locations are approximate

Source: Brower et al., 1977

Figure 3 Average Extent of Ice Front by Month, 1954–1970.

the winter season appears unlikely, but may be possible with ice-breaker support (DOI, 1988). Hence, discharges of drilling muds and cuttings are considered for solid ice, broken ice, and open water in order to bracket the water conditions that may exist during discharge.

SEDIMENT TRANSPORT

Sediment transport and distribution in the Bering Sea is controlled by the dominant tidal currents and the wave field (Sharma, 1972, p. 517). Three different oceanographic domains characterize the Lease Sale area: a mid-shelf domain having strong mixing throughout the water-column; an outer-shelf domain which is deep enough for a separation of surface wind-driven mixing and bottom tidal-related mixing; and a deeper, oceanic domain where mixing is dominated by oceanic processes (Figure 4).

Mass movement of sediment is ubiquitous on the slope in water depths greater than about 200 meters (660 feet) and in the heads of the submarine canyons (Karl and Carlson, 1983, p. 417). Sedimentation rates are highly variable in the area (Karl and Carlson, 1983, p. 431). The average sedimentation rate for the shelf less than 150 meters (500 feet) deep is 14 centimeters (35 inches)/1,000 years, with reported ranges from 2 centimeters (1 inch) to 67 centimeters (170 inches)/ 1,000 years. Accumulation rates of sediments on the upper slope range from 2 to nearly 10 centimeters (1-4 inches)/1,000 years with an average of 15 centimeters (6 inches)/1,000 years. Accumulation rates on the lower slope range from about 4 to 37 centimeters (2-14 inches)/1,000 years with an average of 15 centimeters (6 inches)/1,000 years.

SUMMARY

The Navarin Basin oceanographic conditions can be summarized as follows:

- The Navarin Basin water depth varies from 70 meters (230 feet) to 2,800 meters (9,200 feet), although much of the drilling is expected to occur between 100 meters (330 feet) and 200 meters (660 feet).
- The area is windy throughout the year, with stronger winds in the winter.
- Current speeds are between 2-4 centimeters per second (0.04-0.08 knots) with speeds of 10-15 centimeters per second (0.2-0.3 knots) over the continental shelf and in some eddies. Current speed and water exchange are increased with wind stress.

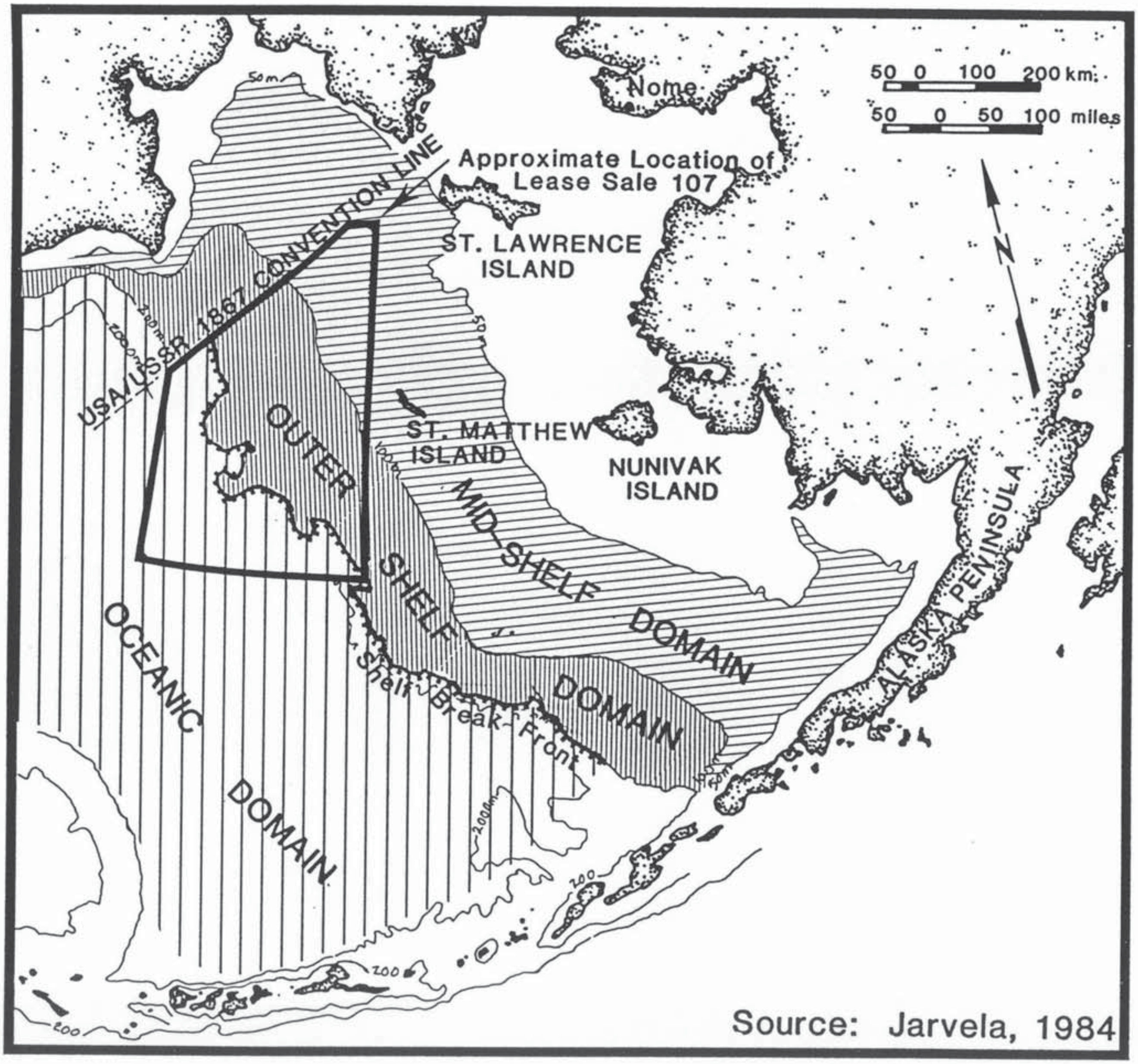


Figure 4 Hydrographic Domains and Fronts on the Southeastern Bering Sea Shelf.

- The water column is stratified throughout the year, but more so in the summer.

- Sea ice occurs from October to June, reducing wave activity and wind stress.

- Sediment is transported by intense winter storms and mass movement, otherwise natural sedimentation rates are low.

THE OFFSHORE OPERATORS COMMITTEE MODEL

The prediction of the fate of discharged muds and tailings relies on a computer model developed by a consortium effort of offshore operators. The Offshore Operators Committee (OOC) model was developed to describe the fate of offshore drilling-mud discharges and has been used in all Ocean Discharge Criteria Evaluations prepared for Alaskan waters. The model simulates the dilution of the discharge plume and makes predictions about the amount of material settling on the bottom. It is discussed in detail in Brandsma et al. (1983, pp. 5-1 - 5-2), Tetra Tech (1984), and EPA (1984, pp. 35-42).

The OOC model uses LaGrangian calculations to track material settling out of a fixed pipe, and describes three phases of plume behavior: convective descent, dynamic collapse, and passive diffusion. A Gaussian formulation is used to sum the three components and to track the distribution of solids to the bottom. Although there are limitations to this model (it does not account for mud flocculation, and it does not simulate produced water), it is considered one of the best available for modeling discharge plume behavior in water depths greater than 5 meters (16 feet) and when surface waves induce variations in water depth of less than 10% (Tarnay, undated).

The model simulates the effluent plume through three phases: the jet-phase or convective descent; the dynamic collapse of the plume; and a later passive-diffusion phase. In addition, the model simulates an upper cloud of material which appears as particles of mud separate from the main plume during its convective-descent phase. The spread of muds and cuttings on the bottom increases with water-depth; in-water dilutions also are greater with increasing depths.

Inputs to the model include data from three parametric categories: drilling-mud characteristics, discharge conditions, and ambient conditions. Drilling-mud characteristics consist of: bulk density; discrete particle classes; and concentration, density, and settling velocity for each particle class. Discharge conditions include rate, duration, orientation, and position of discharge, and rig type. Ambient conditions include water-depth, density profile, current velocity, and wave conditions.

For the model simulations, it was assumed that 10 percent of the mud separated in a linear fashion during the convective descent-phase of the main plume. Initial concentrations of suspended solids in the discharge at 70 meters (230 feet) are assumed to be 1,441,000 milligrams per liter. Ocean currents are assigned a constant magnitude and direction for each model run, although in reality they vary with depth and time. A consequence of this assumption is overestimation of solids accumulations on the bottom and underestimation of dilutions. Typical drilling rig and discharge characteristics are assumed for a rig of dimensions 60 by 70 meters (200 by 230 feet), a discharge nozzle radius of 4 centimeters (1.2 inches), and a vertical angle of discharge. The model assumes the discharge occurs 0.3 meters (1 foot) below the sea surface, although in reality the depths are greater than this to ensure the discharge is below the wave action at the surface. It is assumed that 1,000 barrels per hour are discharged which is at the upper limit of discharge rates (Tarnay, undated). Model assumptions are summarized in Table 6.

The model has been calibrated using field measurements taken at several continental shelf drilling sites including the Gulf of Alaska. The field studies and modeling effort suggest the following conclusions:

- Drilling muds tend to be rapidly diluted over space and time. Concentrations can be reduced three to four orders of magnitude within 100 meters (330 feet) of the discharge, and five to six orders of magnitude within 800 meters (2,600 feet).

- Greatest deposition occurs beneath or slightly downcurrent of the discharge point. In shallower waters, a majority of sedimentation occurs within 100 meters (330 feet) of the discharge point, and background concentrations of trace metals and suspended solids are reached within 1,000 meters (3,300 feet). Deeper waters result in greater dilution, wider dispersion, and lower depth of accumulation.

- Metal distribution in bottom sediments is uneven, generally with a gradient of decreasing concentration associated with distance from the outfall.

COMPUTER SIMULATION MODELING OF DRILLING-MUDS DEPOSITION

The OOC model was used to predict the deposition of drilling-mud discharges in the Navarin Basin. The model runs that are applicable for the area are listed in Table 7. Case 15, discharge to water 70 meters (230 feet) deep in currents of 10 centimeters per second (0.2 knots) and Case 16, discharge to water 120 meters (400 feet) depth in currents of 10 centimeters per second (0.2 knots), represent discharges to open water. Cases 1 and 10 use a

Table 6
Summary of OOC Model Inputs

Category	Variable	Typical Value[1/]
Discharge Conditions	Rate	100-1,000 bbl/h
	Duration	30-60 min
	Angle (from horizontal)	90°
	Depth below surface	0.3 m (1.0 ft)
	Nozzle radius	0.1 m (0.33 ft)
	Rig length	70.1 m (230 ft)
	Rig width	61.0 m (200 ft)
	Forced separation of fine particles	yes
Drilling Mud Characteristics	Bulk density	2.09 g/cm^3 (17.4 lb/gal)
	Initial solids concentration	1,441,000 mg/L
	Tracer concentration	100 mg/L
Receiving Water Characteristics	Current velocity	2-30 cm/sec
	Wave height	0.61 m (2 ft)
	Wave period	12 sec
	Density gradient	<0.10

Source: Tetra Tech, 1984, p. 7

1/ Typical values used for all model runs unless otherwise specified.

Table 7
Summary of OOC Model Inputs for Test Cases[1/]

Case	Depth (m)	Depth (ft)	Surface Currents[2/] (cm/sec)	Surface Currents[2/] (Knots)
1	40	130	2	0.04
5	5	17	10	0.2
10	15	50	2	0.04
15	70	230	10	0.2
16	120	400	10	0.2

Source: Tetra Tech, 1984, p. 13

1/ All cases use a 2.09 g/cm^3 (17.4 lb/gal) mud, initial solids concentration 1,441,000 mg/l, discharged at a rate of 1,000 bbl/h.
2/ Uniform velocity distribution with depth was assumed.

current speed of 2 centimeters per second (0.04 knots) representing discharge under ice or broken ice, and Case 5 uses a water depth of 5 meters (17 feet) representing shunting of muds almost to the bottom before discharge.

The model output gives both drilling-mud deposition and dilution in the water-column. Deposition is discussed below, while water-quality issues (dilution) are addressed in the following section.

DISCHARGE IN OPEN WATER

Normal operating procedure requires several drilling-mud discharges in the course of drilling one well. It is unlikely that there will be repeated deposition in one area except directly beneath the outlet, given the changing tides and a narrow deposition footprint. Thus, Cases 15 and 16 modeled by Tetra Tech (1984) assume the total solids discharged were 114,634 kilograms (52,000 pounds).

For the purposes of our analysis, it was conservatively assumed that all discharges from the drilling of one well are deposited at once. The projected quantity of muds used in drilling one exploratory well in the Navarin Basin is 443,940 kilograms (490 tons [1,097,600 pounds]), or 3.87 times the modeled quantity. The maximum thickness of deposited mud projected by the model was multiplied by 3.87 to accommodate the difference in quantities discharged.

The deposition-pattern along the axis of the current is given for Case 15 (Figure 5) and Case 16 (Figure 6). (Peaks in the histogram are artifacts of the model corresponding to different settling patterns for different particle size classes.) The total amount of discharge is accounted for if it is assumed that the material settles to a uniform depth over an 8 degree arc of a circle.

Approximately 86 percent of discharged solids will be deposited on the seafloor within 914 meters (3,000 feet) down-current of the discharge point for Case 15. In the deeper water (Case 16), approximately 99 percent of the discharged solids will be deposited on the seafloor within 975 meters (3,200 feet) down-current of the discharge point. The maximum depths are 0.14 centimeter (0.06 inch) at 61 meters (200 feet) and 0.47 centimeter (0.18 inch) at 183 meters (600 feet) respectively (Figures 5, 6).

DISCHARGE UNDER BROKEN AND SOLID ICE

The northern edge of the Lease Sale area lies beneath the southern ice-edge boundary. Although drilling is not anticipated during pack-ice conditions, some drilling might occur near the ice

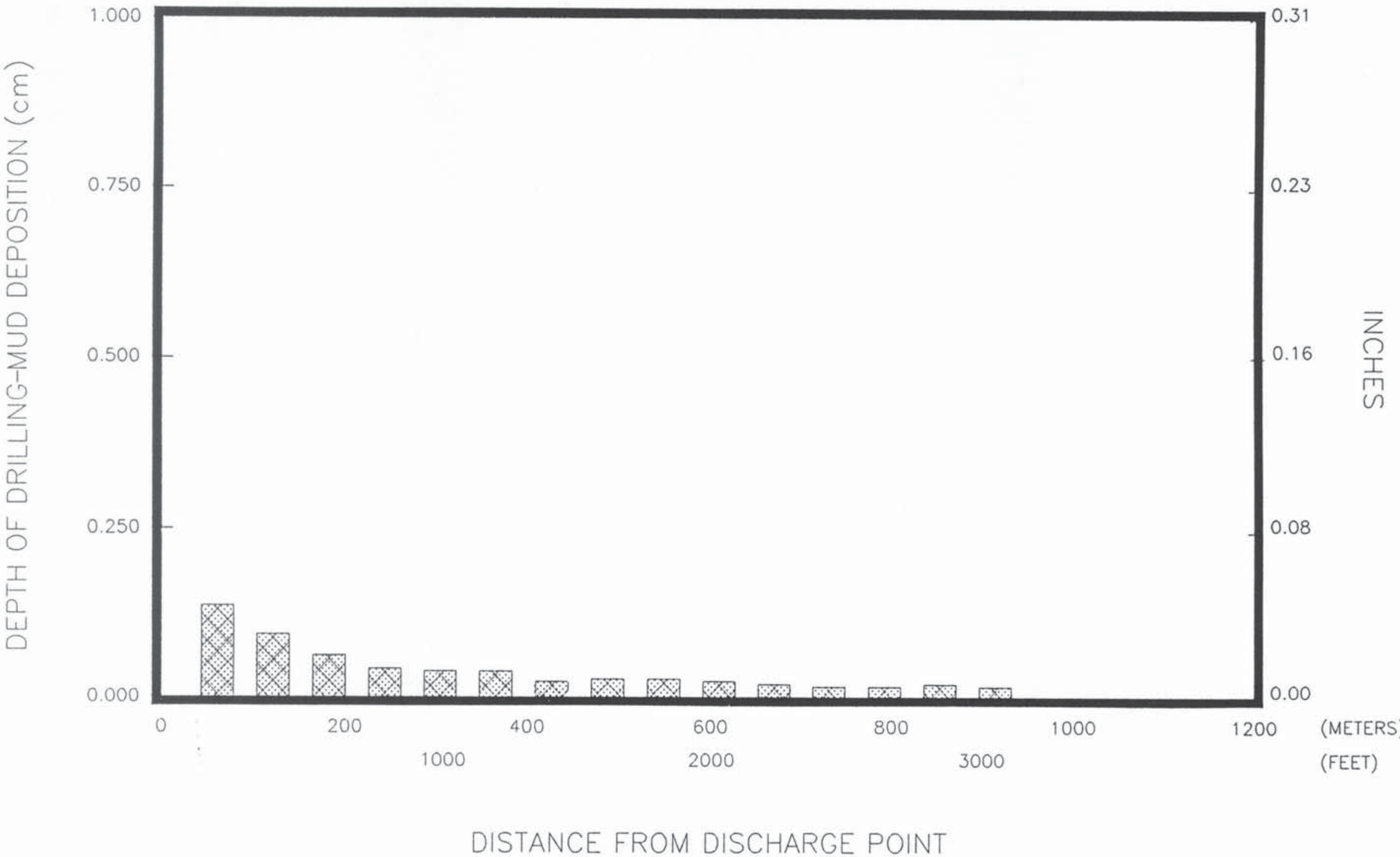


Figure 5. Solids Deposition Pattern Modeled by OOC for a Drilling-Mud Discharge into Water 70 m Deep with Current Speeds of 10 cm/sec.

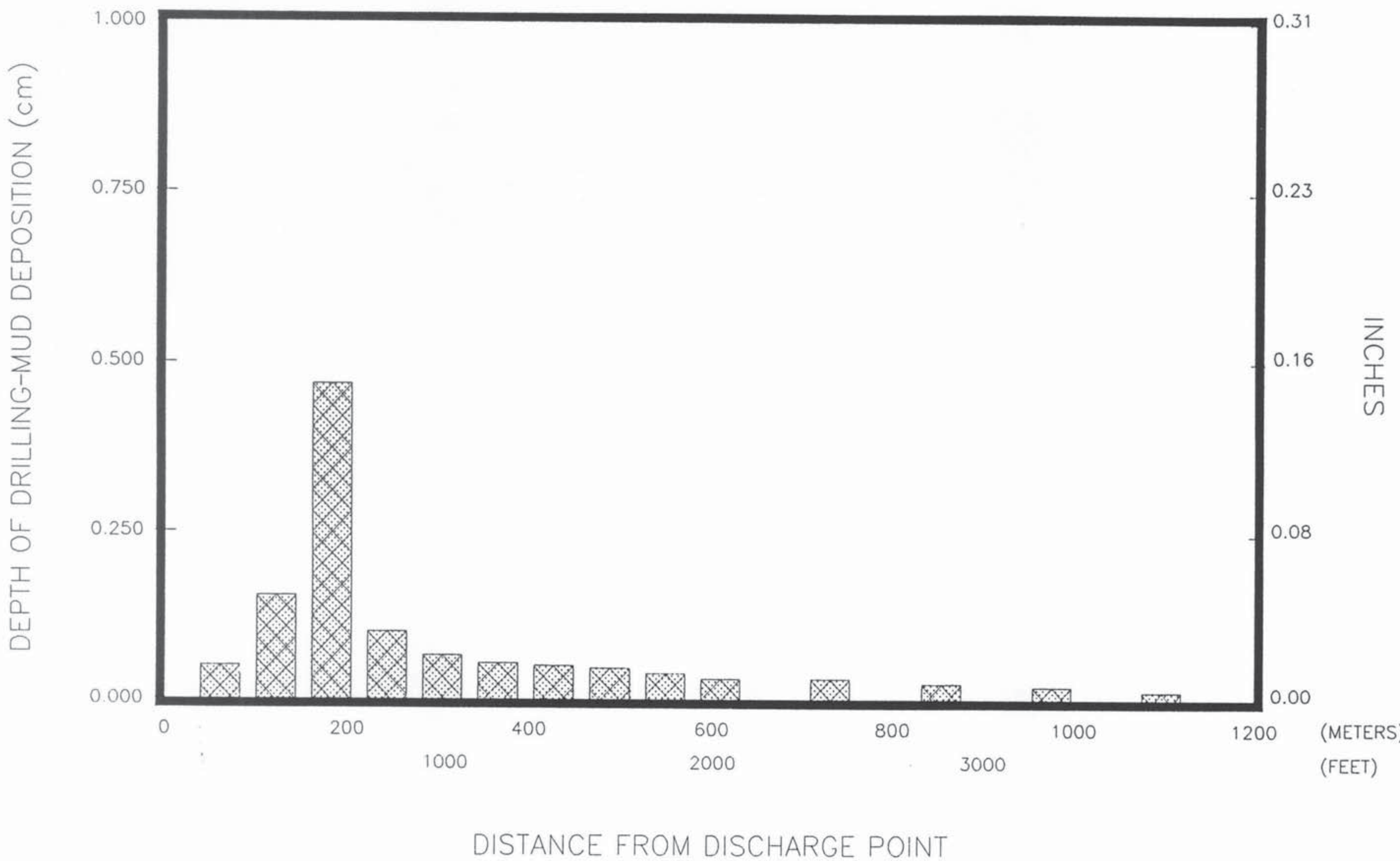


Figure 6. **Solids Deposition Pattern Modeled by OOC for a Drilling-Mud Discharge into Water 120 m Deep with Current Speeds of 10 cm/sec.**

front, which is characterized by loose, drifting, and melting ice. Drilling may occur through the winter with ice-breaker support. The predominant effect of ice is to reduce water-current speed and wind-induced surface currents.

Cases 1 and 10 use current speeds of 2 centimeters per second (0.04 knots). The deposition-pattern along the axis of the current is given for Case 1 (Figure 7) and Case 10 (Figure 8).

Approximately 99 percent of discharged solids will be deposited on the seafloor within 427 meters (1,400 feet) down-current of the discharge point for Case 1. In shallow water (Case 10), approximately 99 percent of the discharged solids will be deposited on the seafloor within 60 meters (200 feet) down-current of the discharge point. The maximum depths are 0.70 centimeter (0.28 inch) at 31 meters (100 feet) and 34 centimeters (13.4 inches) at 31 meters (100 feet) from the discharge point, respectively (Figures 7, 8). The deposition assumes all drilling muds are deposited at once, whereas normal operating procedure is to release muds several times in the drilling of one well. This depth of deposit is highly unlikely to occur given changing tides and currents in the area.

In general, when ocean currents are reduced by ice, deposition occurs rapidly near the discharge point and accumulates to a greater depth than with discharge to faster currents.

DISCHARGE WITH SHUNTING

Shunting increases the depth at which the discharge enters the water, i.e., reduces the functional water-depth. For example, a 30 meter (100 foot) shunt-pipe discharging to a water depth of 70 meters (230 feet) is equivalent to discharging at the surface of 40 meter (130 foot) water depth.

The most conservative case of discharge to 15 meters (50 feet) of water was used (Case 5). The deposition-pattern along the axis of the current is given in Figure 9. Approximately 100 percent of discharged solids will be deposited on the seafloor within 107 meters (350 feet) down-current of the discharge point. The maximum depths are 68 centimeters (26.8 inches) at 15 meters (50 feet) from the discharge point (Figure 9). The deposition assumes all drilling muds are deposited at once, whereas normal operating procedure is to release muds several times in the drilling of one well. It is highly unlikely that this depth of deposit would occur given changing tides and currents in the area. However, there is no advantage to increased dispersion with shunting, and this course of action is unlikely to be adopted.

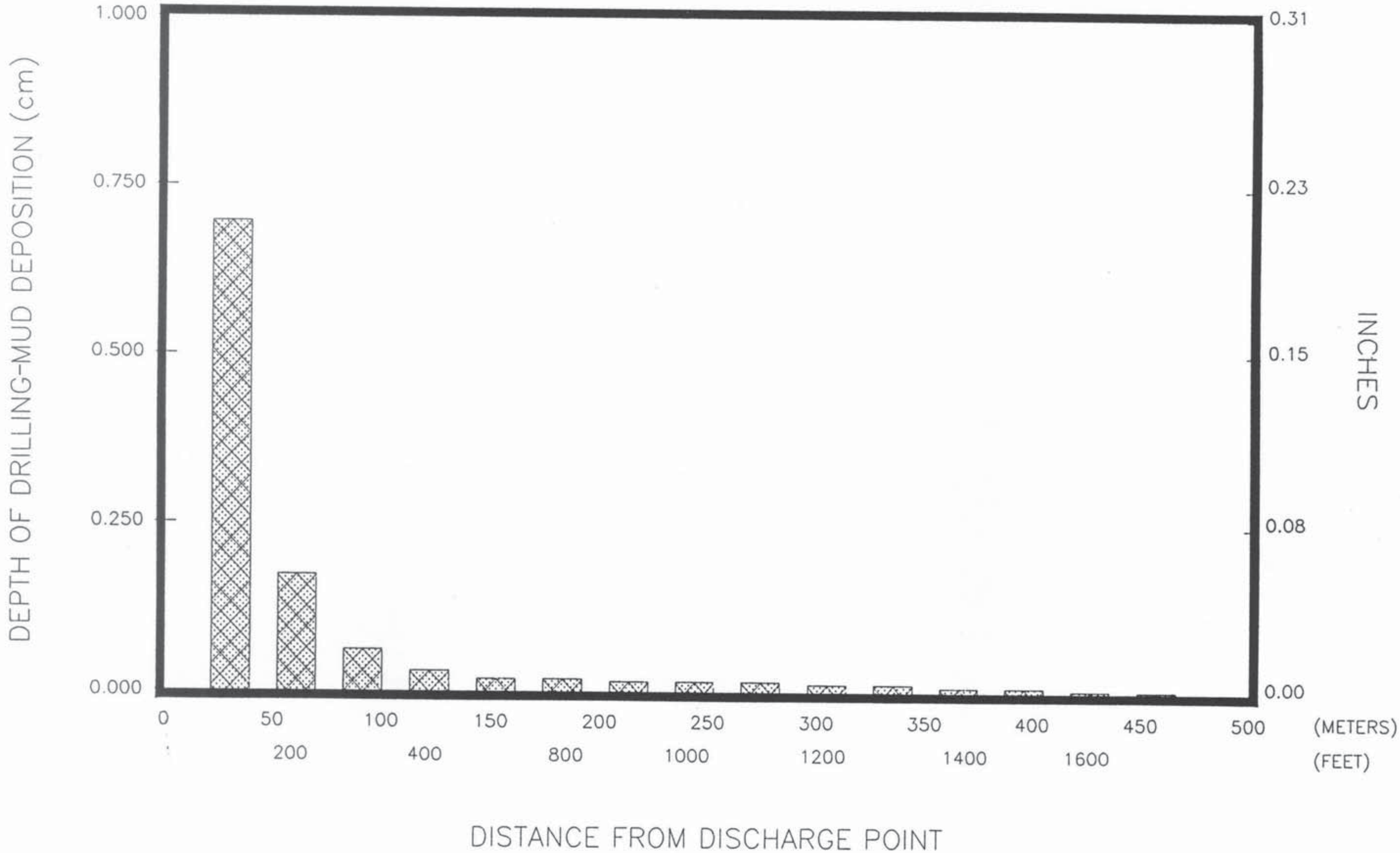


Figure 7. Solids Deposition Pattern Modeled by OOC for a Drilling-Mud Discharge into Water 40 m Deep with Current Speeds of 2 cm/sec

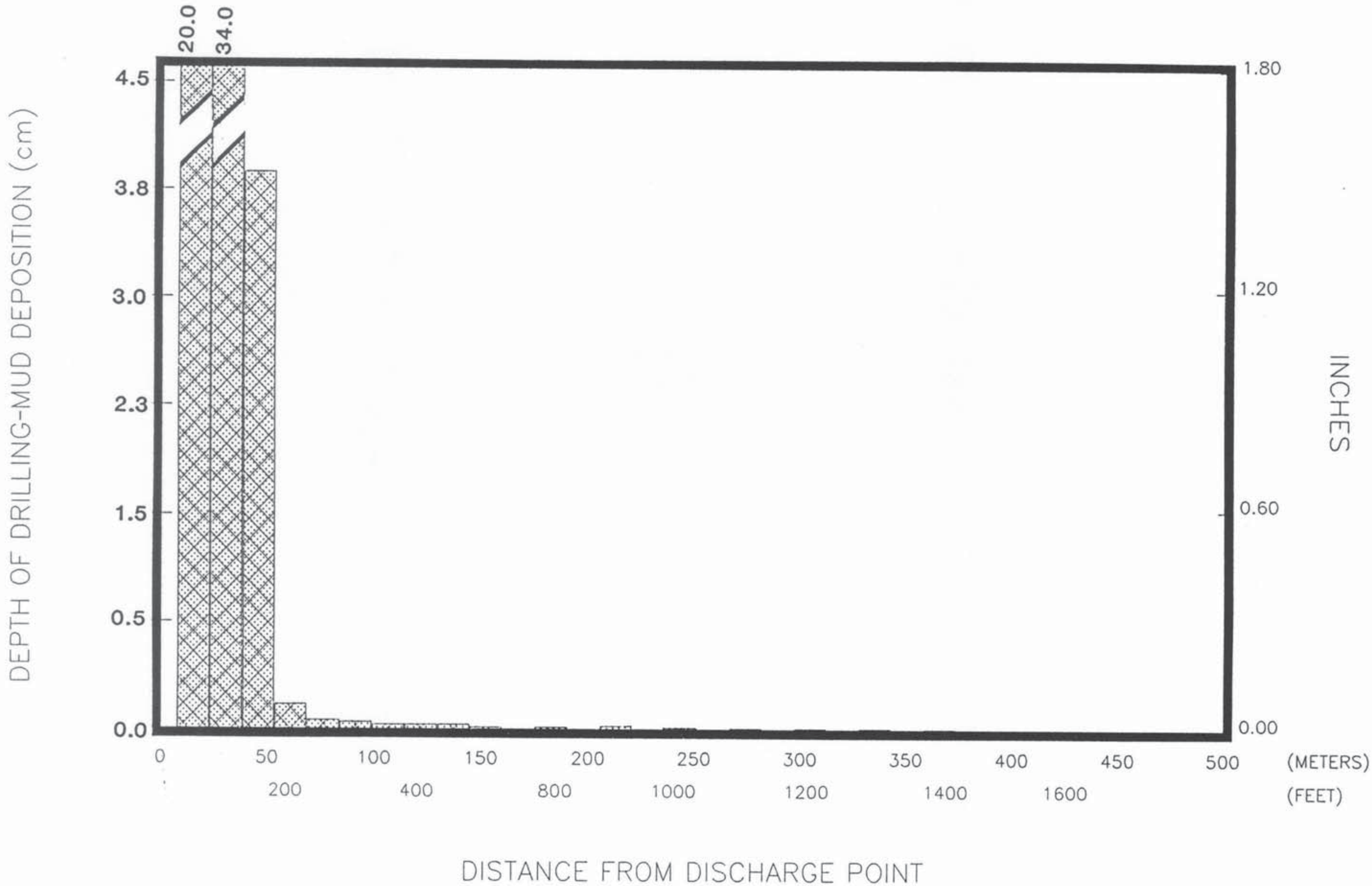


Figure 8. Solids Deposition Pattern Modeled by OOC for a Drilling-Mud Discharge into Water 15 m Deep with Current Speeds of 2 cm/sec.

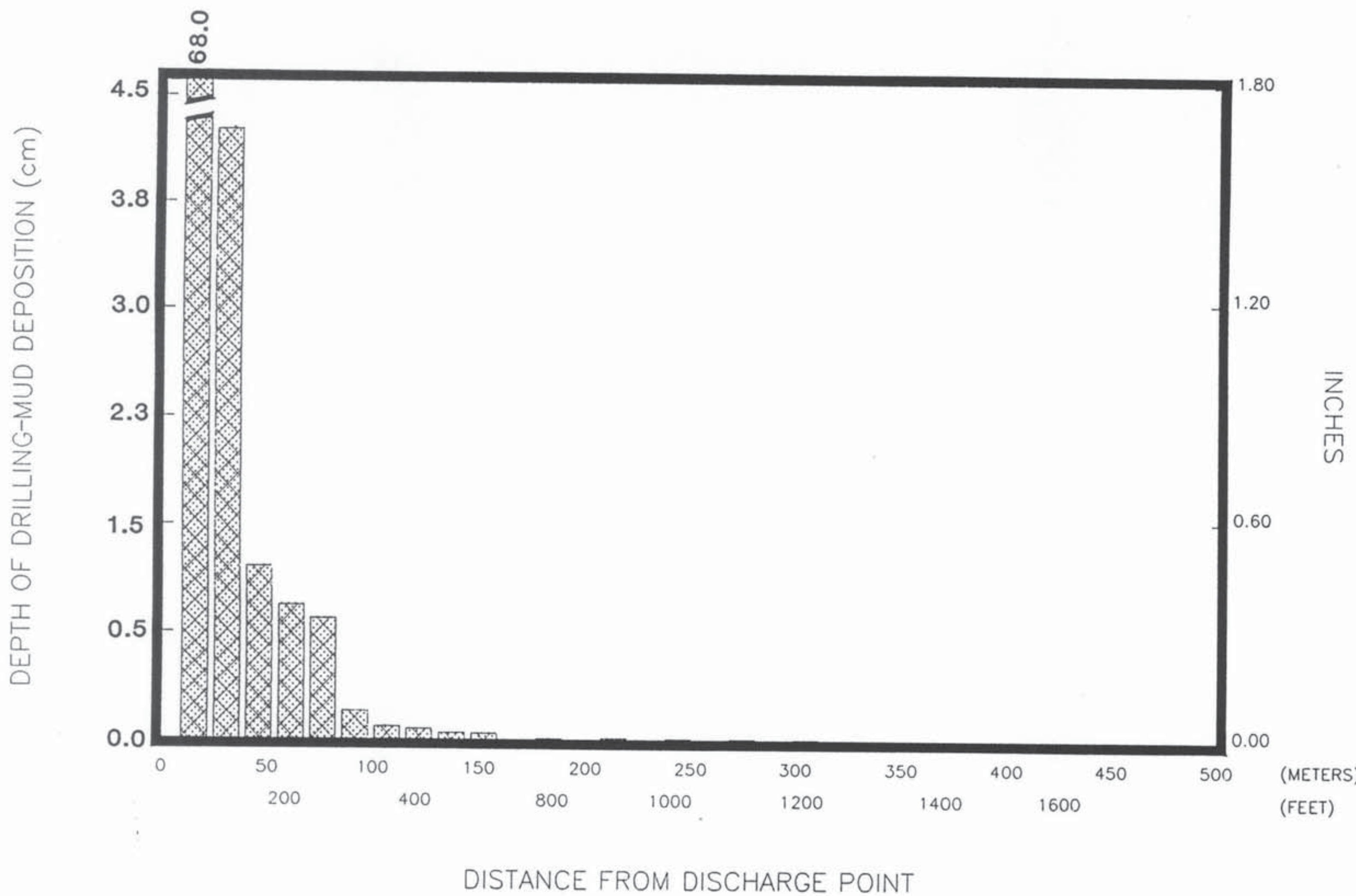


Figure 9. Solids Deposition Pattern Modeled by OOC for a Drilling-Mud Discharge into Water 5 m Deep with Current Speeds of 10 cm/sec.

SUMMARY

The deposition pattern is either very localized but relatively deep, as in Cases 5 and 10 or more widespread and very thin, as in Case 16. The most localized deposition (Cases 5 and 10) is predicted to be up to and over 1 centimeter (0.4 inch) deep for a distance of 50 meters (170 feet) from the discharge point. Assuming each footprint covered an 8 degree arc of a circle, the deposits predicted in the high case scenario (57 wells) would cover 0.8 hectares (2 acres). The most extensive deposition (Case 16) extends 1,000 meters (3,200 feet), albeit very thinly and generally less than 0.05 centimeters (0.02 inches) deep. Assuming each footprint covered an 8 degree arc of a circle, the deposits predicted in the high case scenario (57 wells) would cover 315 hectares (740 acres). These areas are negligible compared with the area of the Lease Sale.

DEPOSITION OF CUTTINGS

Calculations from the OOC model do not include cuttings. Cuttings are expected to be of much coarser grain-size than muds and would be expected to settle rapidly. The majority of cuttings would probably deposit within 100 meters (330 feet) of the well at all depths and expected current speeds. For a worst case estimate of deposition, it is assumed that each deposition pile covers a 360 degree circle around the well. In the high case scenario (57 wells), a predicted 179 hectares (442 acres) would be covered. It is highly unlikely that the cuttings would be deposited completely around the well; instead deeper piles of cuttings are expected in only an arc of the circle.

WATER QUALITY

WATER-QUALITY CRITERIA

The 403(c) regulations allow a 100-meter (330-foot) radius mixing zone for initial dilution of drilling effluent. At the edge of the mixing zone, EPA marine water-quality criteria must be met. Compliance with water-quality criteria is assessed in this section.

Marine water-quality criteria (45 FR 79318, 50 FR 30784, 51 FR 43665, and 52 FR 6213) are stated as acute (or one-hour average concentration) and chronic (or four-day average) values. The chronic criteria are applicable to a relatively constant flux of pollutants. Acute criteria values are applicable to instantaneous releases or short-term discharges of pollutants. The acute criteria are applicable to drilling-mud discharges (Petrazzuolo, 1981, pp. 4-7).

EPA has determined that "acid-soluble" is probably the best measurement for expressing marine water-quality criteria for metals. However, at this time, no EPA-approved method for such a measurement is available to implement these criteria for metals through the regulatory programs of the Agency and the States. The discharges from exploratory phase oil and gas drilling are to open waters and occur intermittantly for a few hours at a time. Dissolved metals concentrations are of most concern since these would be immediately available under these circumstances, and are bioavailable (O'Donnel et al., 1985, p. 485). Soluble and solid metal concentrations in dredged materials (muddy sediments) are given in Table 8. From these data, the ratio of solid to liquid phase in drilling muds is assumed to be approximately 1,000:1.

OOC MODEL RESULTS

The dilution of the discharged drilling muds and associated metals is predicted using the OOC model described earlier in this appendix. The same assumptions and variables outlined in Tables 6 and 7 apply. The dilution achieved at 100 meters (330 feet) from the discharge was modeled for drilling muds typically discharged to Alaskan waters for Cases 1, 5, 10, 15, and 16 (Table 9). A comparison of the output with the EPA water-quality criteria shows all metals are below the EPA one-hour marine criteria (Table 10) by at least one order of magnitude, with the exception of zinc, Case 5, which is 5.5 times below the EPA water quality criteria.

Metals are tightly bound to the solid phase in alkaline waters such as the ocean, and leaching from the muds to the water column is expected to be slight. Any release of dissolved metals to the water column from the muds will be at a much slower rate than the initial release at deposition, and no water quality criteria are expected to be violated.

EFFECTS ON MARINE BIOTA

This section addresses the impacts of drilling muds and cuttings discharges on individual components of the community and on the biotic community as a whole. Particular attention is given to the benthic community and to the potential for heavy metal toxicity to all components of the ecosystem.

COMPOSITION OF BIOTIC COMMUNITIES

INTRODUCTION

Sale 107 encompasses approximately 11.4 million hectares (28 million acres) of the OCS of the western Bering Sea. The biotic community is productive and the area is a major fishing ground for foreign fleets, dominated by Japan. Oceanographic features influencing the substantial biomass are the large, shallow, and flat continental shelf; a steep continental shelf; deep oceanic waters; and seasonal ice fronts.

Table 8
Soluble and Solid Metal Concentrations in
Dredged Materials Dumped at Sea, 1978 and 1979

Metal	Average Concentration Solid Phase mg/kg	Average Concentration Liquid Phase 1/ ppm	Dissolved Constituent Concentration Ratio 2/
Arsenic	4.0	0.0049	0.0012
Cadmium	1.2	0.0016	0.0013
Chromium	33.0	0.0048	0.0001
Copper	30.4	0.0027	0.0001
Mercury	0.3	0.0003	0.0010
Nickel	15.0	0.0068	0.0005
Lead	29.6	0.0068	0.0002
Zinc	68.8	0.0325	0.0005

Source: Bigham et al. (1982, pp. 292-294)

1/ From results of elutriate test.
2/ Liquid phase:solid phase (mg/l:mg/kg).

Table 9
Dilution Factors for Particulates and Dissolved Fractions at the Edge of the Mixing Zone, 100 meters (330 feet) from the Discharge Point 1/

Case	Particulate	Dissolved
1	1:2,015	1:2,170
5	1:4,810	1:200
10	1:11,407	1:1,218
15	1:1,803	1:2,702
16	1:1,437	1:2,503

Source: Tetra Tech, 1984, pp. A-1, A-5, A-10, A-15, A-16

1/ The minimum dilution (discharge:seawater) through the water column is given.

Table 10
Maximum Predicted Dissolved Metal Concentrations in the Water Column at the Edge of the Mixing Zone, 100 m from the Drilling-Mud Discharge Point

a. Concentrations of generic muds at current speeds of 10 cm/sec

Metal	Initial Concentration in the Muds mg/kg[1/]	Maximum Dissolved Concentrations[2/] (µg/L) in Water Depths of: 5 m	70 m	120 m	EPA Marine Water Quality 1-hour Criteria[3/] (µg/L)
Arsenic	17.2	0.086	0.006	0.007	69.0
Cadmium	0.7	0.003	0.000	0.000	43.0
Chromium	908	4.540	0.336	0.363	1,100.0[4/]
Copper	77.3	0.386	0.029	0.031	2.9
Lead	52.5	0.263	0.019	0.021	140.0
Mercury	0.7	0.003	0.000	0.000	2.1
Nickel	9.8	0.049	0.004	0.004	75.0
Zinc	90.4	0.452	0.033	0.036	95.0

b. Concentrations of muds and additives at current speeds of 10 cm/sec

Metal	Initial Concentration in the Muds mg/kg[5/]	Maximum Dissolved Concentrations[2/] (µg/L) in Water Depths of: 5 m	70 m	120 m	EPA Marine Water Quality 1-hour Criteria[3/] (µg/L)
Arsenic	11.8	0.059	0.004	0.005	69.0
Cadmium	5.5	0.027	0.002	0.002	43.0
Chromium	1,820.0	9.100	0.674	0.728	1,100.0[4/]
Copper	47.7	0.239	0.018	0.019	2.9
Lead	1,270.0	6.350	0.470	0.507	140.0
Mercury	19.0	0.095	0.007	0.008	2.1
Nickel	88.0	0.440	0.033	0.035	75.0
Zinc	3,420.0	17.100	1.266	1.367	95.0

Table 10, continued

c. Concentrations of muds and additives at current speeds of 2 cm/sec

Metal	Initial Concentration in the Muds mg/kg[5/]	Maximum Dissolved Concentrations[2/] (µg/L) in Water Depths of: 5 m	70 m	EPA Marine Water Quality 1-hour Criteria[3/] (µg/L)
Arsenic	11.8	0.010	0.005	69.0
Cadmium	5.5	0.005	0.003	43.0
Chromium	1,820.0	1.494	0.839	1,100.0[4/]
Copper	47.7	0.039	0.022	2.9
Lead	1,270.0	1.043	0.585	140.0
Mercury	19.0	0.016	0.009	2.1
Nickel	88.0	0.072	0.040	75.0
Zinc	3,420.0	2.808	1.576	95.0

1/ Metal concentrations data from Table 3, Column 1.

2/ Dissolved concentrations represent 0.1 percent of total concentrations in the muds. (See dissolved constituent ratios in Table 8.)

3/ From 45 FR 79318, 50 FR 30784, 51 FR 43665, and 52 FR 6213. One-hour average concentration not to be exceeded more than once every three years on the average.

4/ Hexavalent chromium.

5/ Metal concentrations data from Table 3, Column 2.

TROPHIC LINKS

The details of phytoplankton and zooplankton growth and trophic relationships in the Navarin Basin are largely unknown, although the general processes are likely to be similar to those in other areas of the Bering Sea.

In the Navarin Basin, the planktonic primary productivity and biomass are extremely high over the outer shelf and open ocean (Figure 10). Large copepod grazers efficiently graze the phytoplankton, consuming between 20-30 percent of the daily production of phytoplankton. Little detritus falls to the benthos, instead it supports a large pelagic biomass, including marine mammals, coastal birds, and commercially important fish. Over the mid-shelf, zooplankton are dominated by smaller copepods which are comparatively inefficient grazers, using only 10 percent of the daily phytoplankton production. Phytoplankton sink to the bottom providing food to the benthic community (EPA, 1984, p. 44).

IMPORTANT HABITATS

An important marine habitat is defined here as an area utilized by a disproportionate abundance of individuals and/or species or an area essential to the ecosystem. While the entire area is used as habitat and for foraging by a number of sea birds, mammals, and fishes, three areas, the shelf break, the ice edge, and the islands, are considered particularly important (Lewbel, 1983).

The shelf break is characterized by high biological productivity. It is a mixing zone of shelf and deep water communities, and the natural border along which many animals migrate and congregate. Species for which the shelf break is important during open-water periods include sperm, fin, and killer whales; northern fur seals; Dall porpoises; fork-tailed storm-petrels; and red-legged kittiwakes. (Latin names are given in Table 11.)

The transitional ice-break edge is an important zone of aggregation for spotted, ribbon, northern fur, and bearded seals; walruses; Steller's sea lions; minke and killer whales; and thick-billed and common murres. The pack-ice edge is considered important habitat for beluga and bowhead whales as many gather in open leads along the south edge of the pack in winter (Lewbel, 1983).

St. Matthew Island, an Alaskan Maritime Wildlife Refuge, is considered important for nesting sea birds (in particular northern fulmars; pelagic cormorants; black-legged kittiwakes; common and thick-billed murres; parakeet, least, and crested auklets; and tufted and horned puffins). Polynyas (open water areas amidst ice)

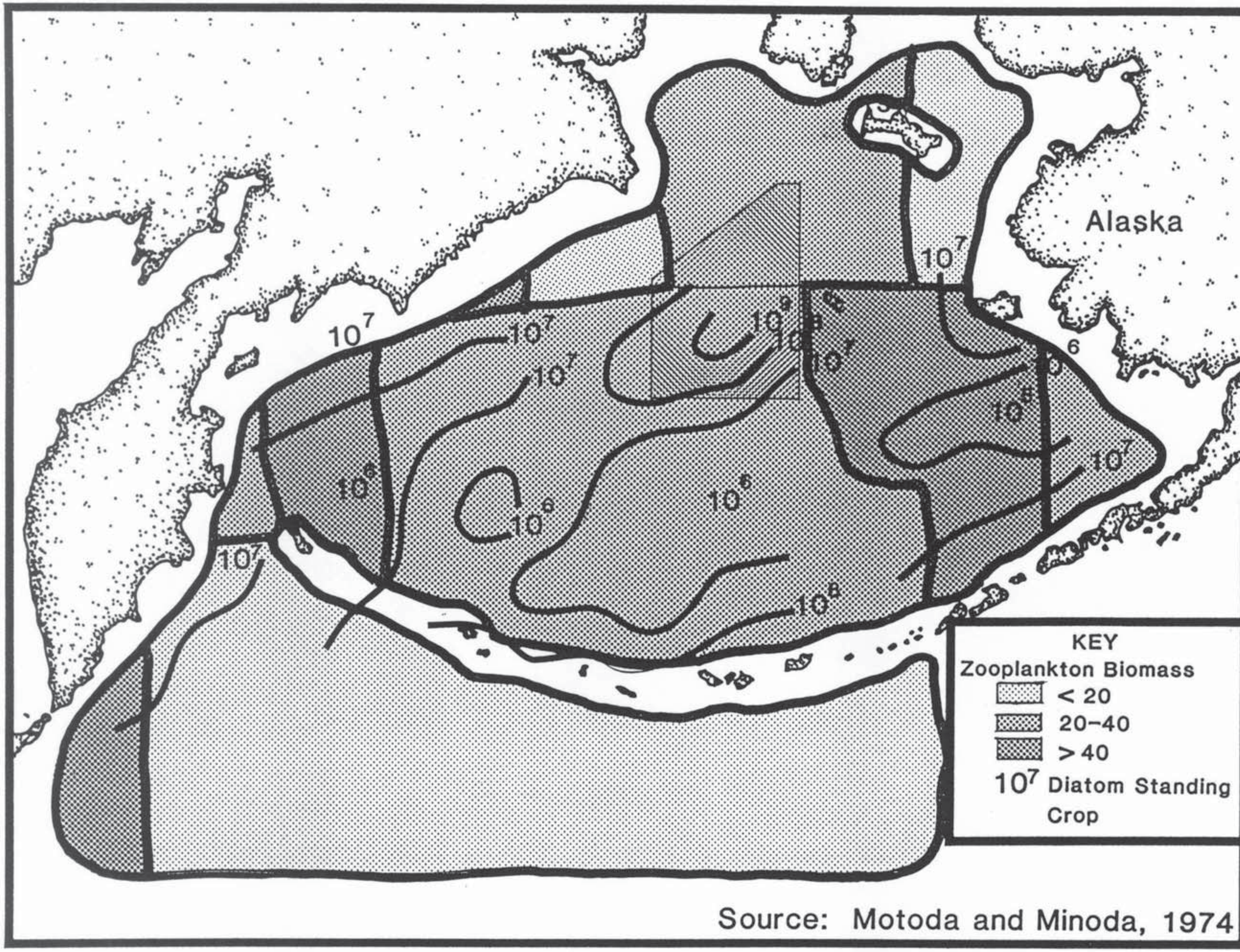


Figure 10. Summer Diatom Standing Crops (cell/m^3) and Zooplankton Biomass (wet weight, g/m^2) in the Bering Sea.

Table 11
Common and Latin Names of Species Described in the Text

Common Name	Latin Name
Invertebrates	
Blue king crab	Paralithodes platypus
Dungeness crab	Cancer magister
Red king crab	Paralithodes camtschatica
Tanner crab	Chionoecetes bairdi
	Chionoecetes opilio
Dock shrimp	Pandalus danae
Humpy shrimp	Pandalus goniurus
Pink shrimp	Pandalus borealis
Fishes	
Atka mackerel	Pleurogrammus monopterygius
Capelin	Mallotus villosus
Flathead sole	Hippoglossoides elassodon
Greenland turbot	Reinhardtius hippoglossoides
Pacific cod	Gadus macrocephalus
Pacific herring	Clupea harengus
Rock sole	Lepidopsetta bilineata
Sablefish	Anoplopoma fimbria
Yellowfin sole	Limanda aspara
Walleye pollock	Theragra chalacogramma
Mammals	
Pinnipeds	
Bearded seal	Erignathus barbatus
Northern fur seal	Callorhinus ursinus
Pacific walrus	Odobenus rosmarus
Ribbon seal	Phoca fasciata
Spotted seal	Phoca largha
Steller's sea lion	Eumetopias jubata
Baleen Whales	
Bowhead whale	Balaena mysticetus
Fin whale	Balaenoptera physalus
Gray whale	Eschrichtius robustus
Humpback whale	Megaptera novaeangliae
Minke whale	Balaenoptera acutorostrata
Right whale	Balaena glacialis

Table 11, continued

Common Name	Latin Name
Toothed Whales	
Beluga whale	Delphinapterus leucas
Dall's porpoise	Phocoenoides dalli
Killer whale	Orcinus orca
Sperm whale	Physeter macrocephalus
Other	
Polar bear	Ursus maritimus
Birds	
Seabirds	
Black-legged kittiwake	Rissa tridactyla
Common murre	Uria lomvia
Crested auklet	Aethia cristatella
Fork-tailed storm-petrel	Oceanodroma furcata
Horned puffin	Fratercula corniculata
Least auklet	Aethia pusilla
Northern fulmar	Fulmarus glacialis
Parakeet auklet	Cyclorrhynchus psittacula
Pelagic cormorant	Phalacrocorax pelagicus
Red-legged kittiwake	Rissa brevirostris
Short-tailed shearwater	Puffinus tenuirostris
Thick-billed murre	Uria aalge
Tufted puffin	Lunda cirrhata
Waterfowl	
Common eider	Somateria mollissima
Harlequin duck	Histrionicus histrionicus
King eider	Somateria spectabilis
Oldsquaw	Clangula hyemalis
Shorebird	
Red phalarope	Phalaropus fulicarius

south of the island provide overwintering habitat for oldsquaw and common and king eiders. The island's location 33 kilometers (20 miles) from the present lease-sale precludes their being greatly affected by OCS exploratory drilling discharges.

It is difficult to consider particular parts of the lease-sale as being more important than others because most species are quite mobile and use much, if not all, of the Lease Sale area. In general, however, the shelf-break zone and outer continental shelf zone appear to be most important to organisms that depend on the pelagic food-chain (zooplankton, pelagic fish, marine birds, and marine mammals), whereas the middle-shelf region is most important to benthic and demersal fish. Endangered marine mammal species are most likely to be encountered in the shelf-break area and over deeper water.

EFFECTS ON BENTHIC COMMUNITIES

DISTRIBUTION

The distribution of benthic species in the Bering Sea has been surveyed in three expeditions by Neiman (1963), Feder et al. (1981), and Stoker (1981). Feder et al. (1981) identified three relatively distinct groups (Figure 11). Group A' with 132 species occurred at depths between 100-200 meters (330-660 feet); the deposit-feeding polychaete _Heteromastus filiformis_ was dominant in terms of density, while the biomass-dominant species was the mud-consuming seastar _Ctenodiscus crispatus_. Group B with 101 species occurred between the same depths; the clam _Axinopsida serricata_ was dominant in numbers and the detrital-feeding brittle-star _Ophiura sarsi_ in biomass. Group D, comprised of 48 species, occurred between 81-103 meters (267-340 feet), and had the lowest density and biomass. It was dominated, both in terms of biomass and density, by the deposit-feeding polychaete _Barantolla americana_ and the clam _Macoma calcarea_. Although benthic species are not uniformly distributed and some important species such as deeply burrowing bivalves were under-represented, general conclusions can be drawn. First, infaunal species richness and biomass are relatively high on the outer shelf and slope, and low on the inner shelf. Second, most of the species are deposit-feeders.

Stoker (1981) found that the benthic population was primarily determined by food availability (levels of primary production), current direction and velocity, and predation. Sediment type was the environmental variable most directly correlated with the distribution of benthos over the Bering Sea shelf, followed by latitude. Neiman (1963) also identified three major benthic associations in the Navarin Basin correlated with water temperature.

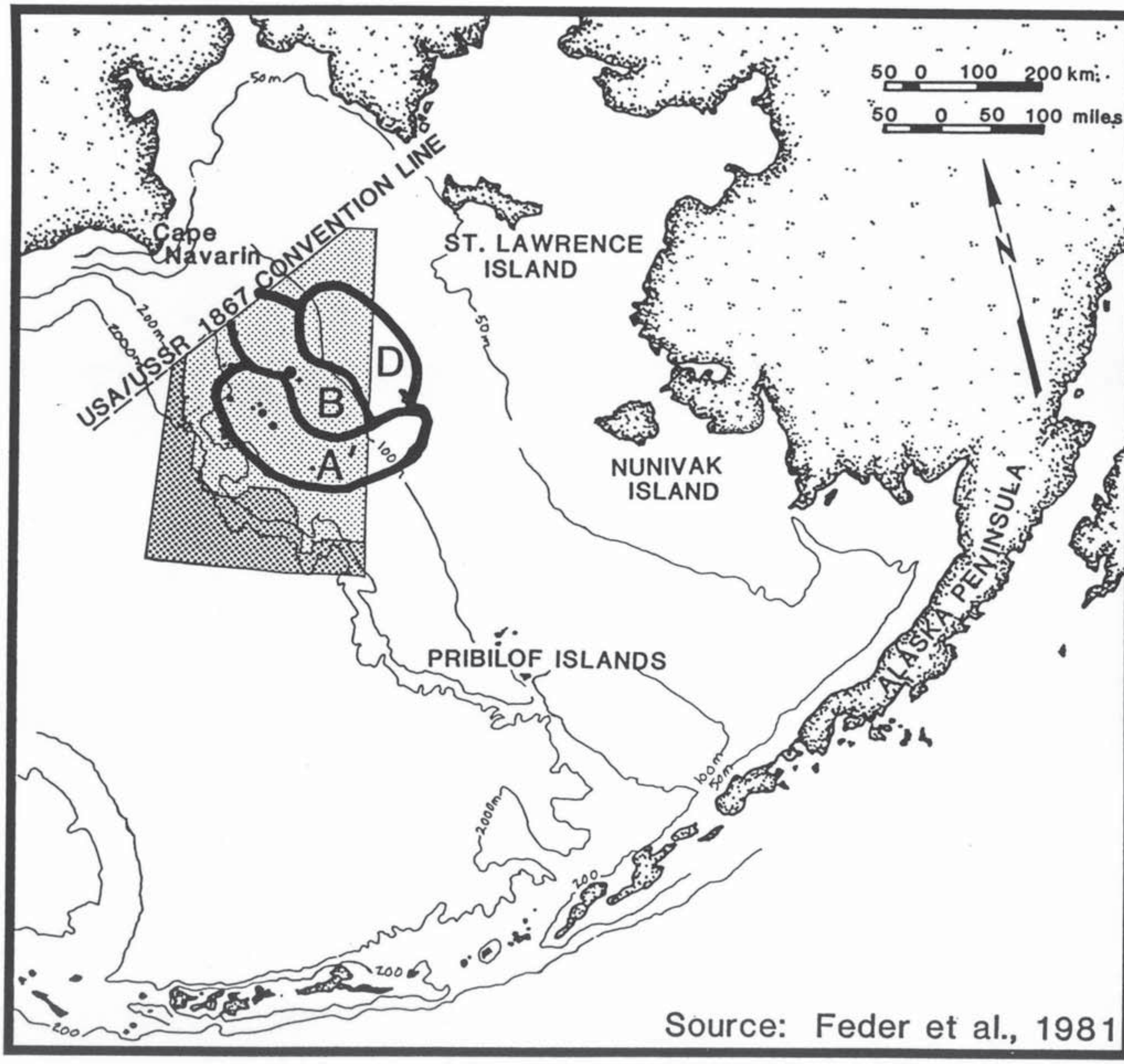


Figure 11. Benthic Associations in the Vicinity of the Lease Sale Area.

Epifaunal invertebrates such as gastropods, amphipods, decapods, asteroids, and echinoids are important components of the benthic community. Many are key prey species or have potential commercial value. Tanner crabs are potential commercial resources in the general area of the Navarin Basin at depths of 40-100 meters (130-330 feet) and greater (Lewbel, 1983). Both species appear to migrate for spawning, although no specific spawning areas are known in the Bering Sea and it is not known if there is a migration route through the Navarin Basin.

The benthos has an important role in ecosystem dynamics, both as mediators for nutrient recycling and as important prey for higher trophic levels, and some species are harvested commercially, notably the Tanner crab. However, the benthic community is sensitive to disturbance, and community structure and function can be altered by disturbance and unnaturally high rates of sedimentation.

EFFECTS OF WASTE DISCHARGES

The National Research Council (NRC) (1983, p. 105) and EPA (1984, p. B-19) have summarized the work of Petrazzuolo (1981), Neff (1981), and Brandsma et al. (1980), identifying the potential detrimental benthic impacts of discharged drilling fluids and cuttings in low-energy environments as:

1) physical smothering of benthic epifauna and infauna;

2) introduction of substances which may have negative effects upon metabolism, health, behavior, or reproductive capability of benthic species; and

3) alteration of sediment chemistry and texture, making it unsuitable for certain species, e.g., interference with burrow construction and feeding or interference with settlement of benthic larvae.

Smothering

The response of benthic organisms to smothering is a function of several interacting factors, including the depth of covering material, the burial time, temperature, and the difference in grain-size of the material relative to the natural sediment (Maurer et al., 1980, 1978).

Studies in the burrowing limitations of 10 bivalves show that the clam _Protothaca staminea_ and _Transennella tantilla_ are most sensitive to burial, with critical depths being 5 centimeters (2.5 inches) (Armstrong, 1965) and 2 centimeters (1 inch) (Maurer et al., 1980), respectively. Arthropods are more mobile than bivalves; the Dungeness crab is the most sensitive to burial of three species studied (Chang and Levings, 1978, p. 409; Maurer et al., 1981, p. 316), being unable to emerge through 20 centimeters (9 inches) of deposit.

The majority of cuttings will be deposited in the vicinity of the well site, smothering the resident biota. Drilling muds will be dispersed over a wider area. Looking only at water depths likely to be drilled in (greater than 70 meters [230 feet]), the OOC model predicts a maximum mud thickness of 0.5 centimeter (0.2 inch) in water currents of 10 centimeters per second (0.2 knots), and 0.7 centimeter (0.3 inch) in water currents of 2 centimeters per second (0.04 knots) (Figures 6, 7). These projected depths are unlikely to affect the benthos.

A worst case scenario for 1 centimeter (0.4 inch) uniform deposition of all muds and cuttings discharged over the six years of exploration is presented. Scenario 1 assumes six wells are drilled, discharging 3,119 cubic meters (4,084 cubic yards) of drilling muds. This would cover 31 hectares (77 acres) to a uniform depth of one centimeter (0.4 inch). Scenario 2 assumes 16 wells are drilled, discharging 8,318 cubic meters (10,890 cubic yards) of drilling muds. This would cover 83 hectares (206 acres) to a uniform depth of 1 centimeter (0.4 inch). Scenario 3 assumes 57 wells are drilled, discharging 29,634 cubic meters (38,795 cubic yards) of drilling muds. This would cover 296 hectares (731 acres) to a uniform depth of one centimeter (0.4 inch). These areas are negligible compared to the total Lease Sale area of 110.4 million hectares (28 million acres).

Alteration of Sediment Characteristics

Alteration of sediment characteristics is expected to affect the benthos more subtly than smothering and over larger areas (Menzie et al., 1980). Menzie et al. (1980) noted reduced abundances of polychaetes, echinoderms, molluscs, and crustaceans up to 370 meters (1,200 feet) from a well site in a low-energy mid-Atlantic OCS site in 120 meters (390 feet) of water. The authors could not attribute the population depressions to any one factor, but instead suggested four possible mechanisms: fish and large epibenthic invertebrates attracted to the drilling area reduced benthic populations through predation; mobile crustaceans emigrated from the discharge area; altered sediment composition adversely affected feeding and survival of some benthic species; and altered sediment composition inhibited larval recruitment. The initial impact zone was recolonized and commenced recovery within a year of cessation of drilling-mud discharge.

Toxicity

Houghton et al. (1980, pp. 1018-1019) identified lignosulfonates and caustic soda (sodium hydroxide), through an effect on pH, as the most acutely toxic components of water-based drilling fluids. The NRC (1983, p. 2) identified diesel fuel (No.

2 fuel oil) and biocides as two of the most toxic constituents which may be present in some drilling muds. However, EPA Region 10 permits for offshore drilling operations have prohibited the discharge of diesel oil and limited the toxicity of drilling muds. The toxicity of new drilling-mud additives must be tested and pass a toxicity based criterion prior to their discharge.

Barium is also of concern since it has been shown to adversely affect some benthic invertebrate species in laboratory experiments (Tagatz et al., 1980, p. 847). At one well site, however, barium was not believed to impact abundance and distribution of benthic invertebrates, even though it was detected in invertebrate tissues (Mariani et al., 1980, pp. 438-439; Menzie et al., 1980, pp. 511-512). Likewise, barium is not believed likely to impact benthic invertebrates in the Navarin Basin.

Generally, the animals tested in laboratory bioassay studies have a remarkably high tolerance to whole drilling muds (EPA, 1984, Table F-1). Dock shrimp larvae had the lowest LC50 (lethal concentration for 50 percent of the test organisms) of any Alaskan organisms tested in an unmixed whole mud (LC50 of 600 ppm) (Carls and Rice, 1984). This value, however, came from tests which used Cook Inlet mud; there is reason to believe this mud was formulated with a component containing hexavalent chromium (Hulse, pers. comm.), which is highly toxic to marine life. The component is no longer formulated with hexavalent chromium, and the 600 ppm LC50 is therefore not considered representative of the muds that would be discharged in the Navarin Basin.

Bioaccumulation

Heavy metals can be highly persistent in the environment and in organisms. Since a variety of metals exist in drilling mud, the potential for metals to bioaccumulate in marine organisms and to biomagnify through food webs, possibly leading to man, are of concern. Benthic organisms are particularly susceptible to bioaccumulation of metals since they live on and in drilling-mud deposits. Mercury, cadmium, and barium are of most concern due either to toxicity and propensity to bioaccumulate or to the possibility of exposure at high concentrations. Anderson et al. (1987, pp. 274-275) report that marine species have demonstrated little bioaccumulation from exposure to sediments contaminated with heavy metals, with the exception of mercury, cadmium, and copper.

Mercury, one of the few metals to biomagnify (increase in concentration up trophic levels) may be in excess of 10 parts per million in some drilling muds. Concentrations of mercury in ocean sediments range from <10 to 2,000 parts per billion with a mean of 100 parts per billion (D'Itri, 1972, p. 12). Although mercury discharged in drilling muds is largely inorganic and not bioavailable, virtually any mercury compound may become a bioaccumulation hazard for organisms since bacteria common to most natural waters are capable of biomethylating the metal (Callahan et al., 1979, p. 14-18). Benthic organisms have been found to bioconcentrate mercury from 0.01 to 0.57 times that of sediment concentrations (O'Conner and Rachlin, 1982, p. 665), although other authors found no evidence for bioconcentration (Neff et al., 1978, pp. 204-208). During exploratory drilling in waters with adequate dilution and dispersion, measurable uptake of mercury in benthos is unlikely.

Cadmium can accumulate to high levels in marine organisms and can biomagnify. Several studies have reported sediment and organism cadmium concentrations to be correlated; cadmium bioconcentration factors for oysters range from 0.008 (Atwood et al. 1979, p. 164) to 40 (Neff, et al. 1978, p. 23) times that of sediment. However, other studies have not supported the validity of bioconcentration factors and have had conflicting results within the same tests (Crippen et al., 1980, p. 636; Mariani et al., 1980, p. 448).

Barium is considered a chemical of concern due to its high concentration in drilling muds and propensity to settle on the substrate, although it has low toxicity. Bioaccumulation has been described in non-Alaskan species. Mariani et al. (1980, p. 448) found barium in benthic organisms to be about 10 times that of sediment concentrations. Expected barium concentrations in the drilling muds are 298 parts per million (Table 3).

Crippen et al. (1980, pp. 636-669) analyzed sediment and benthos for mercury, arsenic, cadmium, lead, and zinc near a drilling site in the Beaufort Sea one year after discharge had ceased. There were suggestions of elevated mercury levels in benthic organisms very near the original discharge site, but no indications of significant bioaccumulation for any of the other metals. However, the mud discharged had mercury levels far in excess of those which EPA Region 10 would approve for discharge under current NPDES permits.

BENTHIC-COMMUNITY RECOVERY

After initial deposition, drilling muds and perhaps cuttings will be dispersed by tides and wind-driven currents. Benthic communities will recolonize the area, although the pioneer species may not be the same as those lost. With time, the pre-existing community will probably recover. Menzie et al. (1980) suggest that benthic communities within the initial impact zone are recolonized and commence recovery within a year following cessation of discharge. The potential for bioaccumulation of metals remains (Crippen et al., 1980, pp. 636-669), although the discharge of toxic pollutants can be regulated through the NPDES permit.

CONCLUSIONS

The benthic community is both prey for and includes commercially important species. The community is affected by exploratory drilling activities by smothering, potential for bioaccumulation of metals, toxic effects of additives, and changing trophic relationships and larval recruitment. The impact of exploratory drilling to the Navarin Basin community is expected to be minor because:

- at worst case, about 300 hectares (800 acres, or 0.003 percent of the lease area) will experience deposition greater than 1 centimeter (0.4 inch) in depth, assuming even coverage of muds throughout six years of drilling activity;

- the control of toxic pollutants and metals is effected by BAT and NSPS effluent limitations; and

- recolonization of the disturbed bottom is expected within a year of cessation of drilling activities.

<u>EFFECTS ON PLANKTONIC COMMUNITIES</u>

The planktonic communities form the first and second trophic levels of the productive community of the Navarin Basin. In addition to being a major portion of the food base for pelagic and demersal food webs, phytoplankton are important because they exert control over nutrient dynamics, and zooplankton include larval forms of commercially harvested species.

DISTRIBUTION

Two groups of phytoplankton are recognized in the eastern Bering Sea: the true phytoplankton consisting of diatoms and flagellates, and ice-algae. The annual cycle of primary production begins with the development of an algal community on the underside of the ice, followed by a bloom at the ice-edge and a later spring bloom in open water. The ice-edge spring bloom accounts for 65 percent of the primary productivity (Jarvela, 1984, p. 56).

Primary production of the epontic (under-ice) algae is low (15 milligrams carbon per square meter per day), although these algae provide an important source of concentrated food and an inoculum for the spring bloom as the ice retreats. The ice-edge bloom is dominated by diatoms which can reach populations of 10^9 cells per cubic meter, higher than any area in the Bering Sea. Up to 227 milligrams carbon per square meter per day is fixed (Horner, 1981, p. 126). The open-water bloom is composed mainly of flagellates and dinoflagellates, a species shift possibly attributable to grazing pressure (Goering and Iverson, 1981, p. 941-943). Average summer diatom standing crop in the Bering Sea, calculated by Motoda and Minoda (1974), is given in Figure 10.

Zooplankton are dominated by copepods, with large, efficient grazers over the mid-shelf and ocean. Commercially harvested invertebrates that have planktonic larvae include: red king crab, blue king crab, Tanner crab, pink shrimp, and humpy shrimp (Curl and Manen, 1982, p. 141), in addition to eggs and larvae of various commercial fish species such as Greenland turbot and walleye pollock. Average summer zooplankton biomass in the Bering Sea, calculated by Motoda and Minoda (1974), is given in Figure 10.

Estimates of annual zooplankton biomass for the southeastern Bering Sea are calculated by Cooney (1981, p. 960) and range from 1.0 to 5.8 grams per square meter for the outer shelf and from 1.3 to 7.6 grams per square meter for the oceanic domain. The shelf-break region is particularly productive and supports a large biomass of higher trophic levels, up to 19.5 grams per square meter.

EFFECTS OF WASTE DISCHARGES

The possible impacts of drilling-mud discharges on marine phytoplankton include:

- decreased primary productivity due to light reduction and increased turbidity;
- decreased primary production or increased mortality due to acute or sublethal toxic effects of trace-metals;
- decreased primary production or increased mortality due to acute or sublethal toxic effects of biocides; and
- stimulation of primary production by trace nutrients in the discharge.

The possible impacts of drilling-mud discharges upon marine zooplankton include:

- decreased growth, altered behavior, or increased mortality due to acute or chronic effects of toxic materials in the muds;
- interference with feeding or respiratory activity due to increased suspended-solids concentration; and
- indirect enhancement or inhibition of zooplankton populations resulting from impacts on phytoplankton.

Toxicity studies have been conducted on the marine algae Skeletonema costatum, in which the effects of drilling muds on cell growth and division were investigated (EG&G Bionomics, 1976a; EG&G Bionomics, 1976b). The EC50 (concentrations at which a designated effect is displayed by 50 percent of the test organisms) with barite was 385 ppm and with freshwater lignosulfonate was 430 ppm without agitation. With agitation, the EC50s increased to 1,650 ppm and 16,000 ppm respectively. Various lignosulfonate formulations were tested in agitated mixes (EG&G Marine Research Laboratory, 1976); the lowest EC50 was 1,325 ppm with IMCO RD-123+spot.

Suspended particulate and liquid phases of a reference drilling mud and a used production mud significantly increased hydranth shedding in the coelenterate Tubularia crocea after 48 hours exposure to 100,000 parts per million (Michel et al., 1986). Only concentrations of 10,000 parts per million of the liquid phase increased coelenterate shedding.

Several factors suggest that the discharge of drilling muds will have a limited effect on plankton:

- The dilution of muds is rapid. At the edge of the mixing zone, dilutions of 200- to 11,400-fold are expected for particulates (Table 9). In most cases, concentrations of 1,000 ppm will probably be present for only 100 meters (330 feet) down-current of the discharge.

- The residence time of the drilling muds will be much shorter than the 96-hour time period of bioassay tests.

- Most toxic metals will be bound to muds and ligands and will not be available in the water column.

- Expected concentrations of metals in the drilling-mud discharges at the edge of the mixing zone are within the EPA water quality criteria, which were established to protect marine life.

- The area affected by detectable discharge plumes is very small relative to the area of the total Lease Sale area.

EFFECTS ON FISH

Approximately 300 species of marine fish inhabit the Bering Sea. Although the fish biomass is high in the Navarin Basin, the number of species is only about 85 (Jarvela, 1984). The low species numbers may be explained by seasonal migrations. Commercially important demersal fish are known to migrate from shallow to deeper waters in the spring. It is not thought that seasonal migrations will be affected by the discharges from exploratory well drilling.

DISTRIBUTION

The dominant and key species in the southeastern Bering Sea is walleye pollock, which is commercially harvested and is a major prey species. Pollock represent approximately 44-59 percent of the total fish and invertebrate biomass in the Navarin Basin (Pereyra et al., 1976, p. 227), and abundant concentrations are found between St. Matthew and the Pribilof Islands and in the Olyutorsk-Navarin area (Moiseev, 1981). Massive schools of pollock occur on the outer shelf and upper slope from the surface to 500 meters (1,650 feet) between the 100 and 200 meter (330-660 foot) isobaths to the west of St. Matthew Island, although they are more common at depths less than 100 meters (330 feet) (Lewbel, 1983). Spawning occurs from March through July, and pelagic eggs and fry are abundant in the Navarin Basin waters (Moiseev, 1981; Morris, 1981, p. 76).

Other demersal fish of commercial importance are Greenland turbot, flathead sole, and Pacific cod. Atka mackerel, Pacific herring, and salmon are commercially important pelagic species. It is not known if other fish species of the Navarin Basin spawn there, although based on spawning information from other areas, most of the fishes probably do, except for herring, capelin, and salmon. Pacific cod and rock sole deposit demersal eggs.

EFFECTS OF WASTE DISCHARGES

Exposure to Discharges

The discharges are expected to be intermittent and fairly brief. Fish are relatively mobile and would be able to avoid stressful regions of the plume during discharges. The fishes most likely to contact deposited materials are demersal species, which are generally less mobile than pelagic species.

Smothering of Demersal Eggs

Demersal eggs could be smothered or otherwise affected if discharge coincides with spawning. Species with demersal eggs include pacific cod, rock sole, Atka mackerel, sand lance, and most sculpins (Cottidae). Little is presently known about smothering or toxic effects of drilling-mud deposition on demersal fish eggs, although, in general, eggs are a particularly sensitive life-history stage. It is assumed that a 1 millimeter (0.04 inch) depth of deposition is the threshold for damage to fish eggs (EPA, 1984, p. C-7).

A worst case scenario for one millimeter (0.04 inch) uniform deposition of all muds and cuttings discharged over the six years of exploration is presented. Scenario 1 assumes 3,119 cubic meters (4,084 cubic yards) of drilling muds are discharged, which would cover 310 hectares (770 acres). Scenario 2 assumes 8,318 cubic meters (10,890 cubic yards) of drilling muds are discharged. This would cover 830 hectares (2,060 acres). Scenario 3 assumes 57 wells are drilled, discharging 29,634 cubic meters (38,795 cubic yards) of drilling muds. This would cover 2,960 hectares (7,310 acres). If the deposition covers areas of spawning concentration the production of fish may be significantly affected. Under actual conditions, however, deposits would not be of uniform depth, and the area covered by 1 millimeter (0.04 inch) or more would likely be substantially less.

Toxicity

The toxicity of whole mud to fish species has been tested. Of the eight Alaskan fish species tested with a total of 24 whole mud samples, all of the 96-hour LC50 values exceeded 1,000 ppm, 95 percent exceeded 10,000 ppm, and 43 percent exceeded 100,000 ppm (EPA, 1984, p. C-8). Of the Alaskan species tested with approved drilling mud, pink salmon fry had the lowest LC50 value (3,000 ppm) based on a volume:volume dilution of continuously suspended drilling mud. The concentration of suspended solids at this LC50 was 1,100 milligrams per liter, suggesting that relatively low concentrations of suspended solids, along with toxicological effects, may affect juvenile salmon survival.

Dilution of solids and dissolved materials are predicted for discharges at 40 meters (120 feet) depth with surface currents of 2 centimeters per second and for discharges in 120 meters (390 feet) of water with currents of 10 centimeters per second. A minimum particulate dilution of at least 1,400:1 is expected in the water column 100 meters (330 feet) from the discharge for discharges of 1,000 barrels per hour in 120 meters (390 feet) of water. (It should be noted that this minimum dilution applies to the area of greatest solids concentration within the plume. Other areas within the plume will experience greater dilutions.) At this dilution, estimated solids concentrations (1,030 milligrams per liter) would be less than 96-hour LC50 for all Alaskan fish species tested. The concentration approaches the LC50 observed for pink salmon fry. However, discharge duration is expected to last no more than a few hours at a time, i.e., less than the 96-hour bioassay test period. Based on this information, acute toxicity outside of the mixing zone is not a significant concern.

Expected concentrations of metals from drilling mud at the edge of the mixing zone (100 meters [330 feet] from the discharge) are compared to EPA water-quality acute (1-hour) criteria (Table 10). All metals are within the criteria which were established to protect marine life. Fish populations are not considered to be at risk from toxicity effects of discharged drilling muds and cuttings.

Bioaccumulation

Heavy metals are the primary constituents of mud and cuttings having potential for bioaccumulation. The majority of heavy metals in the discharge (over 99 percent) are likely to be associated with solids rather than as dissolved materials in the water-column. Reducing conditions that could release some metals from particulates to sediment interstitial water or the overlying water-column are not likely with thin deposition and highly buffered ocean waters.

Fish can bioaccumulate metals either through direct absorption of the water or by ingestion of contaminated food. Because of the small area of water column affected, the intermittent and short duration of the discharge, and the mobility of fish, it is likely that any metals accumulated by fish would be obtained through their diet rather than through absorption from the water column. It is not possible to predict the degree to which an individual fish will accumulate metals from its prey, although it is thought that this is a relatively minor concern given the wide foraging range of fish (EPA, 1984, p. C-10).

Effects on Food Supply

Disposal of mud and cuttings could indirectly affect fish by temporarily reducing their food supplies in the vicinity of drilling rigs. Benthos may be adversely affected by direct smothering, changes in sediment grain-size, and/or a decreased rate of recolonization by larval forms. Alternatively, the discharged materials may provide new habitats and stimulate benthic production.

EFFECTS ON MARINE MAMMALS

Over 20 mammal species, protected under the Marine Mammal Protection Act of 1972, occur within the Navarin Basin Lease Sale area. These include 12 whale species, the Dall porpoise, five seal species, the Steller sea lion, walrus, and possibly the polar bear.

DISTRIBUTION

The spatial and temporal distributions of marine mammals are influenced by environmental factors, including seasonal ice, availability of prey, and water depth.

The dominant marine mammal in the lease-sale area is the northern fur seal. In contrast to other seals, fur seals are generally found offshore (Calkins et al., 1975, p. 2). The shelf-break and outer continental shelf are important to fur seals as foraging and migration areas (Lewbel. 1983; Braham et al., 1982, p. 58). The seals dive to 190 meters (620 feet) in pursuit of fish (pollock and caplin) and squid (U. S. Fish and Wildlife Service, 1988, p. II-38). Ice-associated pinnipeds such as the spotted seal, the ribbon seal, and the Pacific walrus frequent the lease-sale area when ice is present. Polar bears migrate south in winter, historically reaching St. Matthew Island (before 1900), but now the southern boundary appears to be St. Lawrence Island (Lewbel, 1983, p. 43).

Major winter and summer concentrations of walrus occur in the lease-sale area and on St. Matthew Island (Figure 12). The Pacific walrus population, whose productivity is low, has been lowered further by a high rate of fetal abortion. This is possibly attributable to malnutrition, disturbance from aeroplanes, an infectious agent, or a combination of these factors. Its recruitment has been very poor in recent years, due to high postnatal mortality of calves. With such low recruitment and with steeply rising commercial fish catches in Alaska, the population is likely again to be declining (Fay, 1984). Increased human activity in their habitat may pose additional stress which the population is unable to tolerate (Fay, 1984).

Dall porpoise and minke, killer, and beluga whales are the major nonendangered cetaceans frequenting the lease-sale area. Dall porpoise and minke and killer whales are year-round residents of the area, whereas beluga whales are likely to be present only during ice-cover (Braham et al., 1982, p. 59). Minke and beluga whales primarily consume fishes, squid, and other marine mammals; the porpoise feeds on cephalopods and deep-water fishes (Braham et al., 1982, pp. 65, 67). Some minke whales calve in the Navarin Basin area (Lewbel, 1983, p. 39).

Eight endangered mammal species may occur in the lease-sale area. The gray, sperm, humpback, bowhead, and fin whale are expected to occur most frequently. These species are migratory and are most common in the area from spring to fall. Feeding or migration to foraging areas are their main activities in the eastern Bering Sea.

Gray whales migrate north along the shelf-break and outer-shelf in late April through June to the area north of St. Lawrence Island. A significant foraging area is near and north of St. Lawrence Island, where there are areas of high amphipod densities. Bowhead whales occur from January to March in the pack ice from St. Lawrence Island to St. Matthew Island (Lewbel, 1983, p. 35). Due to the spring migration during ice breakup, which follows the west end of St. Matthew Island to the Bering Strait, few bowhead remain in the Bering Sea beyond early May (Lewbel, 1983, p. 35).

Male sperm whales migrate along the Aleutian Island Chain and in deeper waters along the edge of the Continental Shelf to feeding areas around 62°North Latitude. Few are associated with the continental shelf. Humpbacks are widely distributed in the Bering Sea in the summer months. They feed predominately in the west

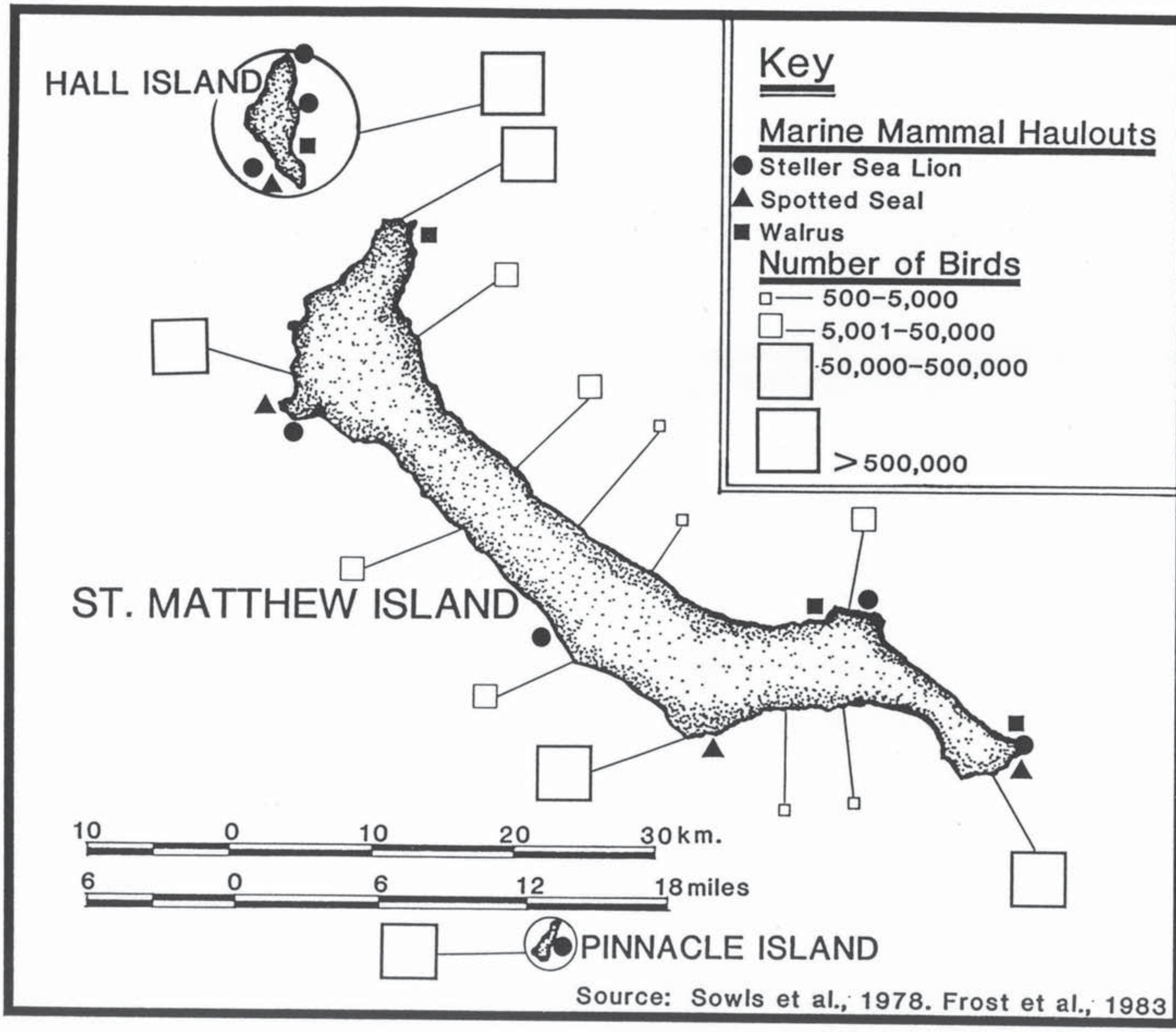


Figure 12. Marine Mammal Haulouts and Seabird Colonies.

Bering Sea near Cape Navarin (U.S.S.R.), north of St. Lawrence Island, and near the Pribilof Islands. Fin whales are also summer visitors, migrating through and feeding in St. George, Norton, and Hope Basins (Lewbel, 1983, p. 37).

Gray whale and Pacific walrus are benthic feeders, and they disturb huge areas of sediment in searching for prey. Gray whale foraging activity was examined in an intensive study north of St. Lawrence Island, a whale population of 16,000 animals disturbed 120,000 hectares (296,000 acres) in one feeding season, excavating pits 0.1-0.4 meters (0.3-1.3 feet) deep. Since they feed on amphipods in clayey substrate, about 172 million tonnes (198 million tons) of sediment are resuspended (Nelson and Johnson, 1987). Walrus eat clams living in sandy sediment, and 200,000 individuals are estimated to resuspend 100 million tonnes (110 million tons) of sediment in one feeding season (Nelson and Johnson, 1987).

EFFECTS OF WASTE DISCHARGES

Exposure to Discharges

Marine mammals are large and mobile, and, in some cases, only migrate through the lease-sale area. Drilling noise and human activity is expected to keep most mammal species at a distance and, therefore, away from direct contact with the discharge plume. Discharges are expected to be made into open water and the plume will be diluted and removed from the water column relatively quickly. Exposure of mammals to the plume, particularly to the most concentrated portions, is unlikely. Exposure to settled mud on the bottom would be possible, particularly in shallower areas of the lease-sale. Benthic feeders such as walrus and gray whale would be expected to have greater contact with deposited mud than pelagic feeders.

Toxicity

Acute and chronic toxicity levels for drilling muds and cuttings have not been determined for marine mammals. The toxicity of drilling mud is generally low, however, and it is unlikely that marine mammals will remain in contact with the discharge for sufficient periods to receive exposure to acutely or chronically-toxic concentrations in either the water-column or the bottom sediments. Since materials will be discharged intermittently and dispersion and dilution are rapid within a short distance of discharge, any direct acute or chronic toxic effects on marine mammals are judged to be unlikely.

Bioaccumulation

Little is known concerning metal concentration in Alaskan marine mammals, although mercury concentrations in beluga whale and other species has been observed to exceed the criteria for human consumption in some areas (EPA, 1984, p. F-23). Any bioaccumulation of metals is most likely to occur through ingestion of contaminated food sources rather than through absorption of metals from the water column.

Benthic feeders are most likely to bioaccumulate metals from feeding on contaminated prey and incidental ingestion of drilling-mud sediment. Gray whales are most at risk, since they feed on the pioneer species of amphipod (Nelson and Johnson, 1987) that would probably rapidly settle on drilling-mud discharges. Their feeding behavior would resuspend anaerobic muds with a high content of dissolved metals such as the highly toxic methyl mercury. However, the major feeding areas are north of St. Lawrence Island, and few are expected to feed among drilling-mud depositions in the Navarin Basin (U. S. Fish and Wildlife Service, 1988, p. II-48).

Mammals feeding on fish and plankton are less likely to accumulate metals than those feeding on benthic species because animals in the water column are less likely to be exposed to elevated metals concentrations in the water column or deposited muds.

Insufficient information exists to predict the extent to which an individual mammal would feed on contaminated food, or the extent to which any particular prey species or mammalian predator would bioaccumulate heavy metals. However, bioaccumulation of heavy metals in mammals from drilling-mud and cuttings discharges during exploratory drilling is judged not to be a significant concern based on:

- the relatively limited volume of the wastes discharged;
- the limited number of exploratory wells;
- the limited areal extent of elevated heavy metal concentrations in the water-column and sediments; and
- the mobility of mammals which allows selection of food from a variety of uncontaminated as well as contaminated locations.

Effects on Food Supply

Disposal of mud and cuttings could indirectly affect marine mammals by reducing benthic populations serving as food. The disposal of mud and cuttings can smother benthic organisms, redistribute populations, change sediment characteristics, or discourage recolonization of an area by larval forms. It could also impact a number of these species, particularly those with demersal eggs, should discharge coincide with spawning. The degree of impact depends on number and location of wells in Sale 107.

However, discharge of drilling mud and cuttings during exploratory drilling is unlikely to cause any significant reduction in marine mammal food supplies, given the small number and size of the areas where prey species could be reduced, compared to the total area of available food supply.

EFFECTS ON MARINE BIRDS

DISTRIBUTION

The western Bering Sea is a major habitat for marine birds. Conservative population estimates range from 34-46 million birds in the summer and 28-40 million in the winter (Hunt et al. 1981, p. 712). About 45 species of seabirds (excluding loons, grebes, waterfowl, and shore birds) occur regularly in the Bering Sea, of which nine are nonbreeding visitors. At least 6 million birds, or 60 percent of the breeding birds in the eastern Bering Sea, breed on the Pribilof, St. Matthew (Figure 12), and St. Lawrence Islands, including two species (the least auklet and the red-legged kittiwake) that are endemic to the Bering Sea.

The short-tailed shearwater is the most abundant species, feeding on euphausiids, squid, and fish over the continental shelf, generally in areas with water depths of less than 50 meters (160 feet). Abundant pelagic species include fork-tailed storm-petrels, least auklets, red phalaropes, and murres. Storm-petrels consume small fish, cephalopods, and euphausiids near the surface; least auklets eat large copepods; and phalaropes eat plankton fish larvae and crustaceans. Murres and many of the bird species in the area consume pollock.

Several features of the Navarin Basin are likely to be important to seabirds, based on observations from other parts of the Bearing Sea. The shallow continental shelf, the shelf break, and the deep ocean offer a variety of feeding niches, combined with high planktonic productivity over the shelf break. The seasonal ice front enhances planktonic production. The ice front is particularly important to ivory gulls and murres. Polynyas along the lee of islands are important winter habitats to murres and sea ducks (oldsquaws, eiders, and Harlequin ducks) (Jarvela, 1984, p. 82).

EFFECTS OF WASTE DISCHARGES

Exposure to Discharge

Discharges are expected to be intermittent and relatively brief. Since discharge activity is distant from land, nesting sites are not expected to be affected. It is not expected that marine birds will be directly affected by exposure to the discharges, since, due to their mobility, they are able to avoid stressful regions of the plume during discharge.

Toxicity

No data exist concerning the acute toxicity of drilling mud to birds. Toxicity could only result if birds are exposed directly to discharges or indirectly through contaminated food. Because discharge is intermittent, dilution occurs rapidly during discharge and much of the material settles quickly following cessation of discharge, direct contact between marine birds and the concentrated plume is not expected to be extensive. In areas such as Cook Inlet where highly turbid waters occur naturally, little seabird foraging occurs, apparently due to the inability of birds to visually locate prey (Gould pers. comm.). Feeding that has been recorded in highly turbid water is limited to situations in which prey organisms are concentrated at the surface, such as during gray whale feeding activity, and does not include diving birds (Gould pers. comm.). Drilling-mud discharges are not expected to concentrate prey organisms near the surface. Toxic effect from direct contact with discharged material are, therefore, expected to be minimal.

Ingestion of contaminated food organisms is possible; however, due to the limited areal coverage of a discharge plume, the intermittent nature of the discharge, and the mobility of birds, it is highly unlikely that a significant portion of a bird's diet would be contaminated. Impacts from ingestion of contaminated food organisms are, therefore, also highly unlikely.

Bioaccumulation

No data exist concerning heavy metal bioaccumulation in marine birds from drilling-mud and cuttings discharges. Pelagic birds foraging offshore (e.g., nonbreeding gulls, murres) may obtain some heavy metals via contaminated prey. Birds are likely to forage in uncontaminated areas as well as contaminated areas, but it is not possible to predict the extent to which a given individual or species will forage in either location. However, metal accumulation is judged not to be a significant concern because of the limited number of wells to be drilled, limited extent of contamination in benthic or pelagic prey species, and the mobility of birds and most prey species. Measurable impacts would be likely only if the drilling was to affect large portions of major feeding areas for extended periods of time.

Effects on Food-Supply

A number of bird species feed on fish and invertebrates. Bird populations could be reduced if their prey were significantly reduced in quantity or were unavailable to predation due to increased turbidity.

Two sea bird groups that are known to have had poor reproductive success in recent years are the kittiwakes and the murres (Jarvela, 1984, p. 88). The chief prey of both these species is walleye pollock, whose population is heavily affected by commercial fishing. It is unlikely that discharges from exploratory oil well drilling will significantly affect pollock populations.

Populations of fish and invertebrates in the water column are not expected to be significantly affected by drilling discharges due to the intermittent nature and rapid dilution and dispersion of discharges and the mobility of the species. Food supply for birds is therefore not expected to be reduced.

Some prey may be unavailable to seabirds due to increased turbidity from drilling mud discharges. Because discharges are intermittent, of short duration, and dilution and dispersion occur rapidly, significant quantities of prey organisms are not expected to be made unavailable to birds. Significant effects on bird populations are, therefore, highly unlikely.

COMMUNITY EFFECTS

Based on an assessment of the sensitivities and susceptibilities of Alaskan marine organisms to drilling mud and drilling mud components, the biological communities in Sale 107 do not appear to be at unreasonable risk from toxicity caused by limited, offshore exploratory-phase discharges of drilling mud. However, the potential for significant effects on all communities increases when large-scale production is considered.

Overall, larvae and planktonic organisms are most sensitive to constituents in the water column, and effects on the biota will primarily be a function of dilution and dispersion of the discharge plume and duration of discharge. Since dilution is rapid and metals concentrations are within EPA water quality criteria (set to protect marine life) within 100 meters (330 feet), effects to the plankton biomass are expected to be transient and localized.

The benthic community is the most likely to be affected physically and toxicologically because of potential exposure to large amounts of drilling-mud solids. Effects on the benthos will be primarily a function of the depth and areal extent of solids deposition. Since the area affected is small, population depressions in the benthic community are not expected to have serious impacts on marine species higher up on the trophic web.

Metal bioaccumulation by benthic organisms, and subsequent biomagnification through the trophic links, is of some concern. Existing data, however, indicate minimal bioaccumulation of metals during exploratory drilling because of the limited volumes of drilling muds and cuttings discharged.

Benthic-community structure is changed in the immediate vicinity of the discharges due to smothering, in particular by cutting piles which may be a few meters high and 100 to 200 meters (300 to 600 feet) in diameter in a non-dispersive environment (Battelle Ocean Sciences, 1987, p. 3-11). However, the fresh habitat is rapidly recolonized, and field studies show little change in benthic communities one year following cessation of drilling activity.

In conclusion, irreversible and significant impacts to the marine biota are not anticipated due to the limited areal extent and quantities of discharge associated with Sale 107 exploratory drilling activities. Additionally, the planned 24 exploration and delineation wells are to be drilled over a period of 8 years. Even in the unlikely event that the impacts become cumulative or synergistic under as yet unspecified conditions, data do not exist that would predict adverse impacts with any degree of certainty.

COMMERCIAL, SUBSISTENCE, AND RECREATIONAL HARVESTS

The Navarin Basin commercial trawl fishery is conducted by foreign fleets and is dominated by Japan. Japan also conducts a high seas mother-ship gillnet operation in and near the area (Jarvela, 1984). Fishery effort is directed towards trawling for pollock, with Pacific cod and sablefish being of secondary importance (Table 12). Harvests from the Navarin Basin account for significant percentages of the total Alaskan catch (Table 12).

Shrimp were harvested by Japanese ships until 1966 when over-fishing curtailed commercial harvests. The Bering Sea crab C. opilio stock is very important to the fishing industry (Table 12). After depressed populations resulted in closure of the area to harvesting until 1984, the populations are increasing due to good harvesting practices (Johnson, 1987). It has been suggested that the Norton Sound/St. Lawrence Island area is a huge C. opilio nursery (Johnson, 1987).

Crab are unlikely to be smothered by the predicted depths of drilling-muds deposition. Their prey, (bivalves, brittle stars, sea urchins, sand dollars, polychaetes, and shrimp), are more vulnerable to smothering. However, the area of potential smothering is predicted to be small, representing only a fraction of the Navarin Basin area, and crab populations are probably more impacted by fishing practices than by deposits from exploratory oil and gas drillings.

Subsistence and recreational harvests do not occur in the Navarin Basin because of the great distance from inhabited land. However, species harvested in other areas probably use the Navarin Basin during some portion of their lives, particularly bowhead whales, herring, and salmon.

Table 12
Commercial Fish and Crustacean Harvests in the Eastern Bering Sea for 1986-1988, and Percentage of the Alaskan Catch

	1986		1987		1988	
	Million Tons	%	Million Tons	%	Million Tons	%
Flatfish	299,353	99	242,151	98	368,612	99
Greenland turbot	8,408	84	6,512	68	6,021	88
Rock sole	2,902	100	10,307	96	22,405	99
Yellowfin sole	208,598	100	181,128	100	218,055	100
Other	79,444	99	44,204	99	122,131	99
Rockfish	915	56	1,866	52	1,856	39
Pacific Ocean perch	625	78	1,278	64	1,459	67
Other	290	35	587	39	397	15
Roundfish	1,333,829	93	1,373,145	95	1,485,320	95
Atka mackerel	14	0.04	118	0.4	167	0.8
Pacific cod	131,152	95	143,470	91	188,585	97
Sable fish	3,518	54	4,113	52	3,192	48
Walleye pollock	1,199,112	96	1,225,444	100	1,293,376	97
Other	0	-	0	-	0	-
Ground fish	1,645,606	94	1,625,719	95	12,833	97
Crustaceans						
Tanner crab (C. opilio)	0.02	-	0.025	-	0.03	-

Source: Fog, pers. comm.; Griffin, pers. comm.

Bioaccumulation of heavy metals in fish or shellfish captured for human consumption is of most concern in the assessment of harvest quality. Insufficient data are available to accurately assess the accumulation of metals from drilling mud discharges in marine organisms. However, harmful effects from barium, the most abundant heavy metal in drilling muds, would likely require ingestion of unreasonably large amounts of seafood within a short period. Also, bioaccumulation of metals in fish and shellfish is not likely to decrease overall harvest quality because of the relatively limited volume of waste discharge and the limited areal extent of dissolved metal concentrations in the water column. Bioaccumulation may occur to a small extent in sedentary species such as snails; however, low-level bioaccumulation is not expected to adversely affect humans. Exploratory drilling activity in Sale 107 is not likely to cause a significant problem because of the limited area of impact and low level of activity.

HUMAN HEALTH IMPACTS

Adverse human health effects from drilling muds are unlikely to result from the limited exploratory phase discharges as direct human exposure is low. Human health affects are most likely to result from chronic ingestion of marine organisms that have accumulated high levels of metals. Three metals are of concern: mercury and cadmium because they biomagnify in food webs, and barium, which is present in large concentrations in drilling muds. Barium could be accumulated in marine organisms but human ingestion of enough contaminated seafood in a short enough period of time to pose a human health threat is unlikely. Petrazzuolo (1981, p. 5-1) assessed human health risk based on reported barium concentrations in biota and concluded that a human would have to eat 5-15 kg (11-13 pounds) of contaminated seafood in a short period of time (biological half-life of barium is less than 24 hours) in order to be at risk. This event is highly unlikely to occur.

Organic mercury is readily taken up by marine biota and accumulates in the liver and kidney (Hamer, 1986). Mercury accumulation by pilot whales can be high enough to pose a health risk to human inhabitants of the Faroe Islands (Andersen et al., 1987), and seal meat has been found to contain high levels of mercury. Many organisms possess a metal-binding protein known as metallothionein that is thought to detoxify the accumulated metal (Hamer, 1986).

Existing data on metal bioaccumulation are inadequate for the quantification of potential long-term human health impacts. However, there does not appear to be a significant concern about marine bioaccumulation during exploratory drillings since drilling mud discharges are periodic and of small volume, and significant human health impacts are, therefore, not expected.

EFFECTS OF LAND-DISPOSAL

Land-disposal of drilling muds and cuttings is generally unattractive as sites fill and new disposal locations must be found. However, land-disposal has been considered for operations off the Canadian coast (Lamm, 1982) and in the Beaufort (Drajnich, 1983; Cooper Consultants, Inc., 1986a) and Chukchi (Cooper Consultants Inc., 1986b) Seas. However, if the drilling-mud composition was such that ocean disposal would violate the conditions of the NPDES permit, or if there is insufficient information to determine that there will be no unreasonable environmental degradation to the discharge site, on-land disposal is the only option.

On-shore disposal options include placing the mud in existing quarries, building pits or sumps, or direct land-disposal. For each of these options, shipping traffic, docking facilities, and haul roads are required.

The construction of pits or sumps removes land from other uses. The magnitude of land loss is dependent on the volume of waste to be disposed and the amount of time that would be required to reclaim the lands with vegetative cover. Snow can accumulate in the pits over winter, and flooding is a danger during spring break-up. Furthermore, drilling muds and fluids that could not be safely disposed of at sea probably contain toxic materials such as oil and grease, heavy metals, synthetic and natural organic compounds, high concentrations of salt, and have a high biochemical oxygen demand.

Accumulated pit water must be disposed of to avoid a lagoon forming which may attract waterfowl and other wildlife and pose potential hazards to them. Land-disposal of pit-water can stress the vegetation; for example, willows are particularly sensitive to salt concentrations over 4,000 milligrams per liter (Cooper Consultants, Inc., 1986a, p. 33).

There are no known studies dealing with the effects of direct application of drilling muds to tundra vegetation and soils (Cooper Consultants, Inc., 1986a, p. 33). However, it is expected that fresh muds are more saline than pit-water and might therefore cause greater physiological damage to tundra plants. There is potential for physical or mechanical damage due to the weight of the muds and to smothering and burial of the vegetation. Heavy metals may be taken up by plants and transmitted through the food-chain, and oils and grease can be directly toxic to vegetation (Cooper Consultants, Inc., 1986a, p. 34).

The nearest land mass, St. Matthew Island, is a National Wildlife Refuge and is not an environmentally acceptable option for the land-disposal of drilling muds. The nearest inhabited land are St. Lawrence Island, 97 kilometers (60 miles) away and the Pribilof

Islands, 180 kilometers (110 miles) away. Inhabitants of the islands depend on groundwater, replenished from rainfall, for their drinking water (DOI, 1986, pp. 5-69, 6-57). The soils on the islands are gravelly loam overlain by shallow silt loam (U. S. Fish and Wildlife Service, 1988, p. II-121). There is considerable potential for drinking-water contamination from land-disposal of drilling muds and cuttings. Land-disposal of drilling muds on St. Lawrence Island and the Pribilof Islands is not considered a practical nor an environmentally acceptable option.

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